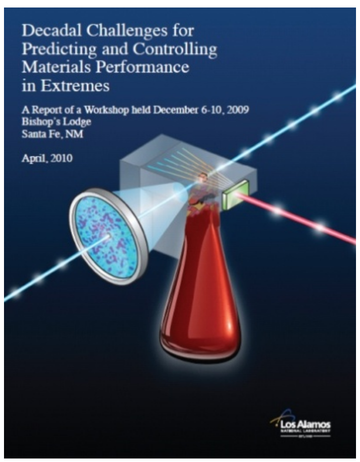
# MaRIE:

(**Ma**tter-**R**adiation **I**nteractions in **E**xtremes)

## *An Experimental Facility Concept Revolutionizing Materials in Extremes*




John Sarrao
Los Alamos National Laboratory

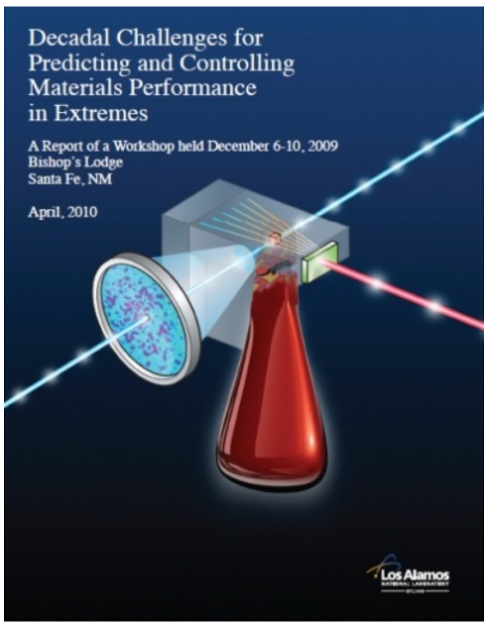

**General Talk**
**12/20/10**

# Outline

- Current Definition: The Why and What of MaRIE
  - *Why would you want to build a 50 keV XFEL and couple it to a MW-class proton accelerator?*
- Acquisition Strategy and Facility Realization
  - *Why might Los Alamos be an interesting place to do this?*
- Where we need your help
  - *How might you become involved, especially in advance of the first 'call for proposals' in ~ 2020?*

## Materials research is on the brink of a new era – moving from observation of performance to control of properties

- **The confluence of improved experimental capabilities (e.g. 4th generation light sources, controlled synthesis and characterization, …) and simulation advances are providing remarkable insights at length and time scales previously inaccessible**




**New capabilities will be needed to realize this vision:**

**In situ, dynamic measurements**

*simultaneous scattering & imaging*

**of well-controlled and characterized materials**

*advanced synthesis and characterization*

**in extreme environments**

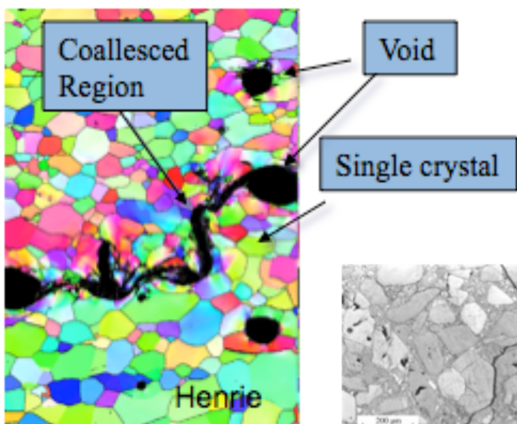
*dynamic loading, irradiation*

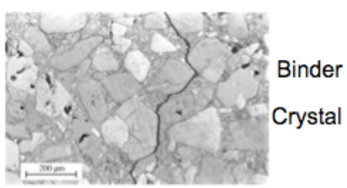
**coupled with predictive modeling and simulation**

*materials design & discovery*

# Understanding materials in extreme environments is key to weapons program success in the future

MATERIALS MATTER




Microstructure of PBX 9501

## Current Stockpile

- Prediction of materials lifetime & failure

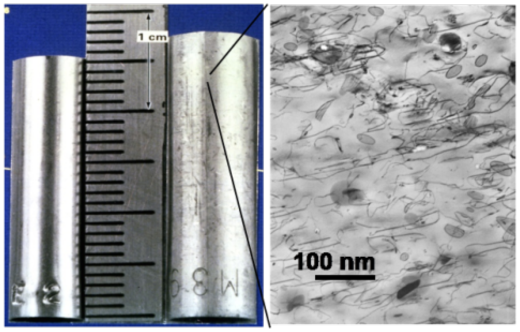
## Rebuild & Lifetime Extension

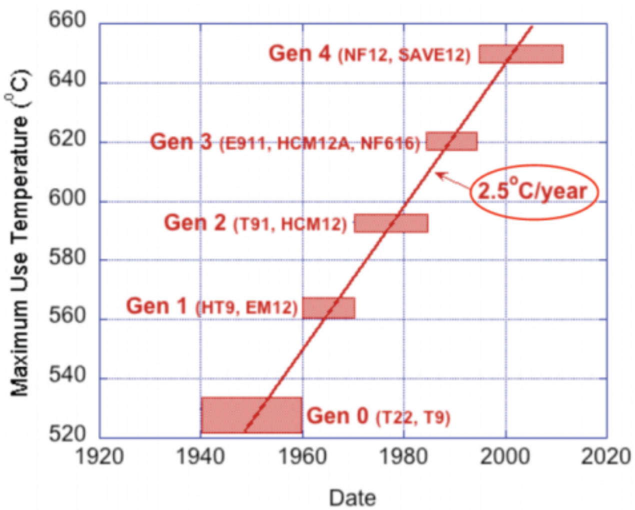
- Materials ‘by design’ rather than re-learning old processes

## Weapon performance

- Effects of microscale materials properties on dynamic performance for key physics

# Materials behavior limits the performance of advanced energy systems needed for energy independence



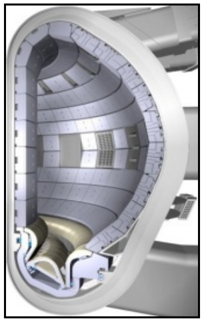




**Life extension, safety of existing reactor fleet**

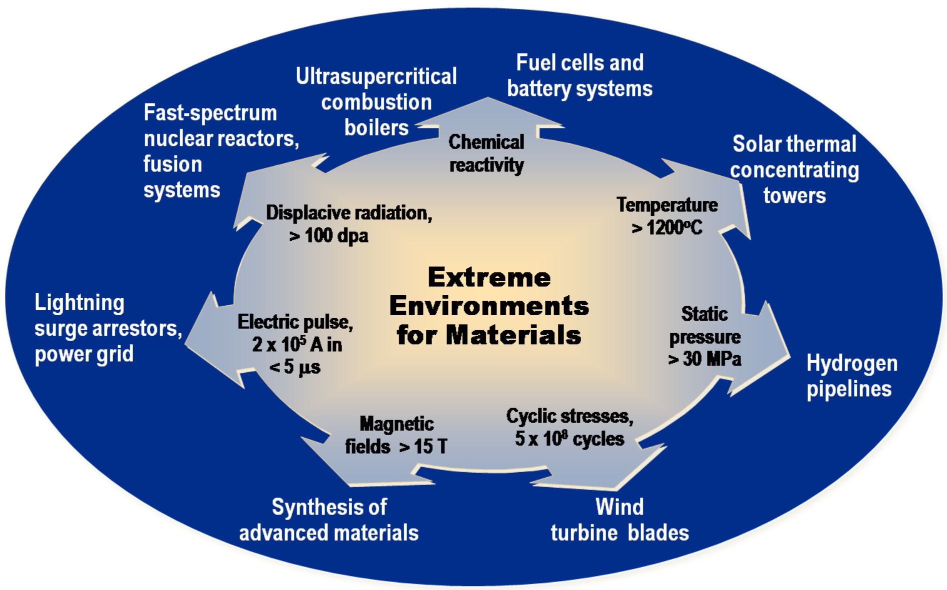
**Improved affordability for new reactors**

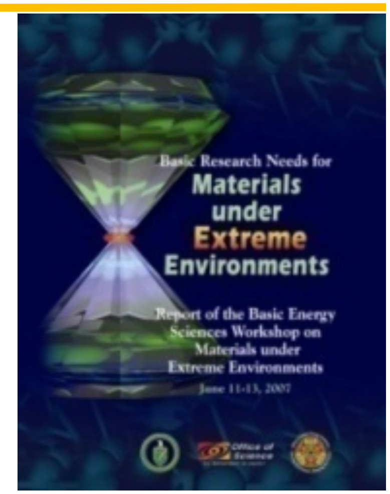
**Sustainable fuel cycles**

**Fusion Reactor first wall materials**



# The needs for materials in extremes are many; the challenge is common: revolutionary advances in controlled functionality

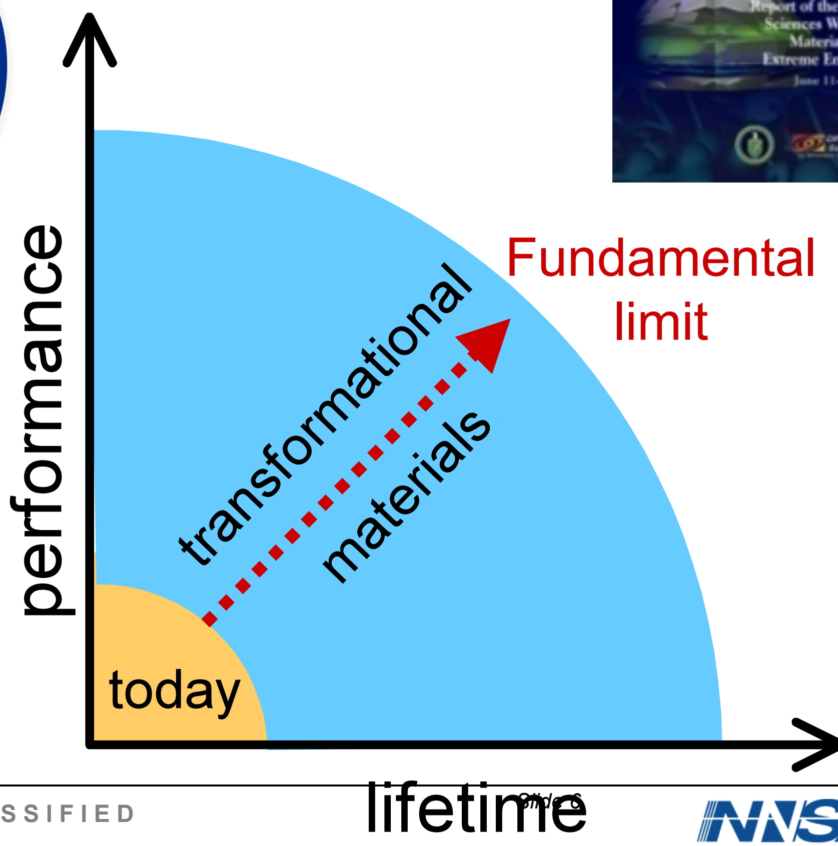



**We need to enable a transition:**

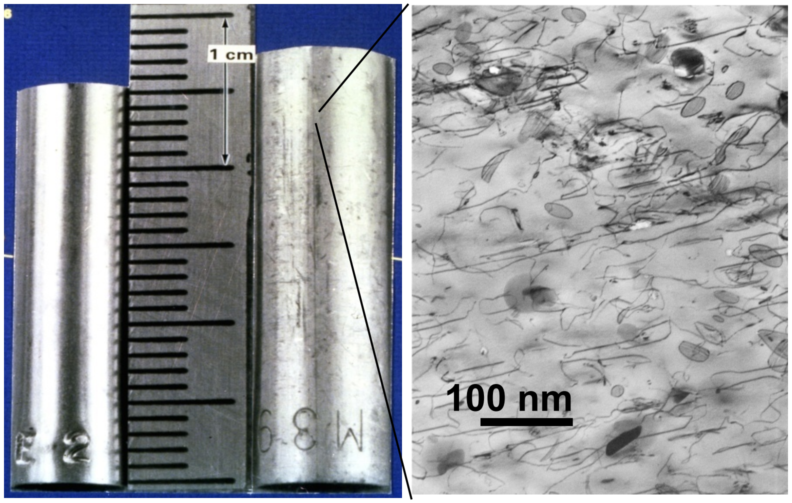
**from observation and validation**

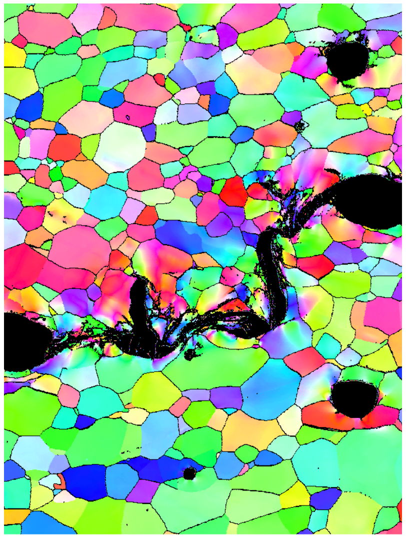
**to prediction and control**



# The “micron frontier:” Bridging the gap between atomic understanding and bulk performance

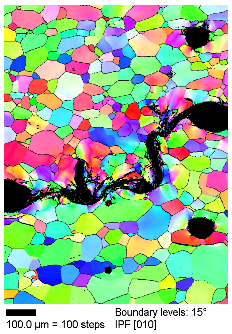
~ 1 $\mu$m is the domain of defect consequences and microstructure interactions that drive materials strength, damage evolution, etc.



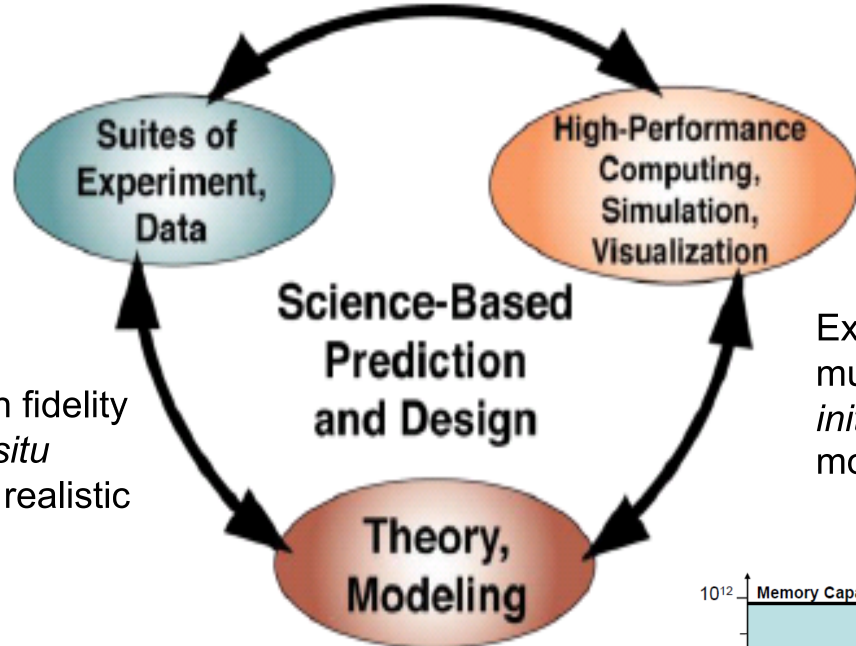



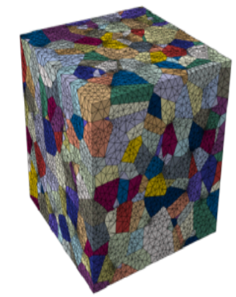

Dynamic, stochastic processes in extreme environments dominate the phenomena that we do not understand

# Next generation simulation capabilities and experimental tools will enable discovery science at the micron frontier



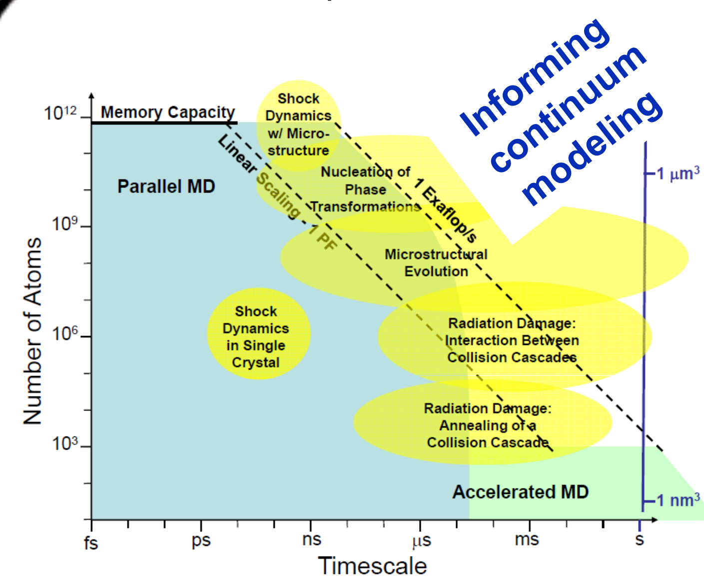

Controlled fabrication, high fidelity characterization, novel *in situ* diagnostics, generation of realistic extreme environments, …



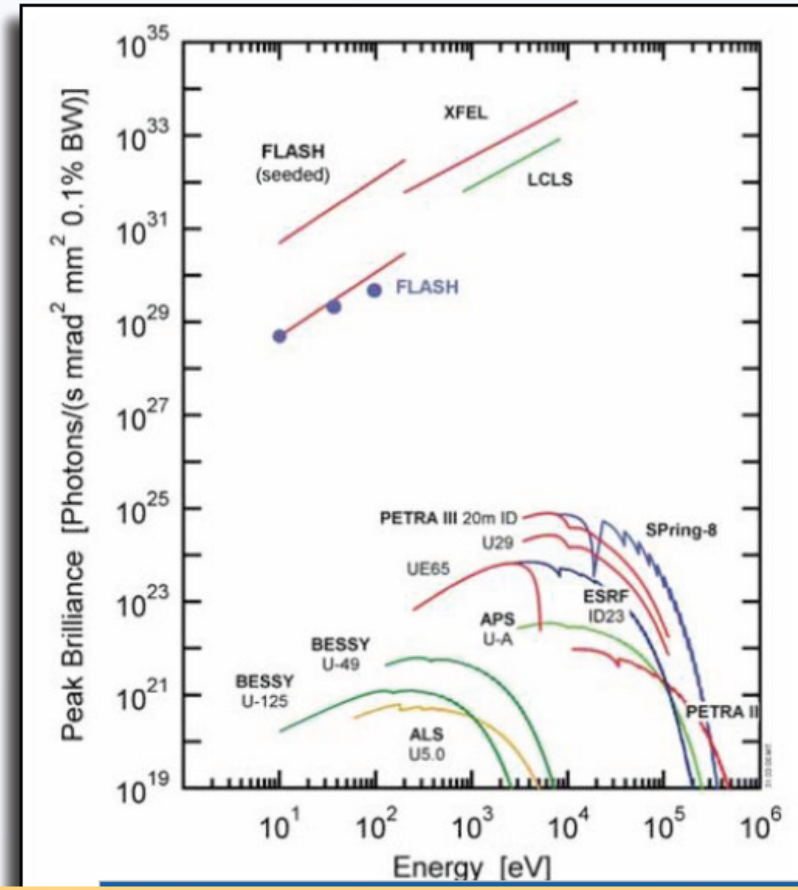



Exascale computing, multi-scale, multi-physics simulation tools, *ab initio* methods applied to larger, more complex materials, .

Multi-scale approaches to connect fundamental scales to bulk properties, defect generation and evolution, …



# 4th generation light sources, producing brilliant, coherent photons, provide a unique opportunity (especially when coupled with broader, integrated capabilities)

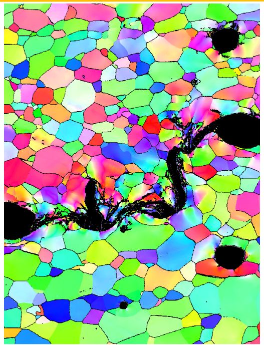



| | FLASH (6.0 nm) | LCLS (0.15 nm) | XFEL (0.1 nm) |
|---|---|---|---|
| mJ/pulse | 0.3 | 2.6 | 3.7 |
| Photons/pulse | $9 \times 10^{12}$ | $2 \times 10^{12}$ | $2 \times 10^{13}$ |
| GW | 3 | 26 | 37 |
| Peak Brightness | $2.0 \times 10^{30}$ | $1.2 \times 10^{33}$ | $8.7 \times 10^{33}$ |
| Bandwidth (%) | 0.6 | 0.3 | 0.1 |
| Hz | 50 | 100 | 50 |
| Date | 2005 | 2009 | 2015 |

*100 fs time resolution, sub-nm spatial resolution, high peak power (>$10^{17}$ W/cm$^2$), full transverse coherence*

# MaRIE : What does success look like?

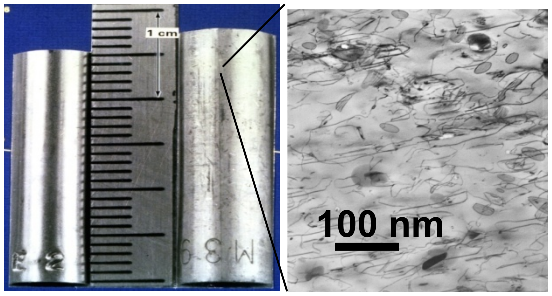
- **Predicting materials performance, including failure, in extremes of pressure and strain for multi-phase materials**



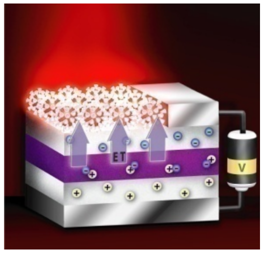

Materials failure under dynamic load

- **Developing radiation resistant structural materials and fuels by design**

- **Exploiting complex materials and architectures for next generation electronics**




Radiation-induced swelling



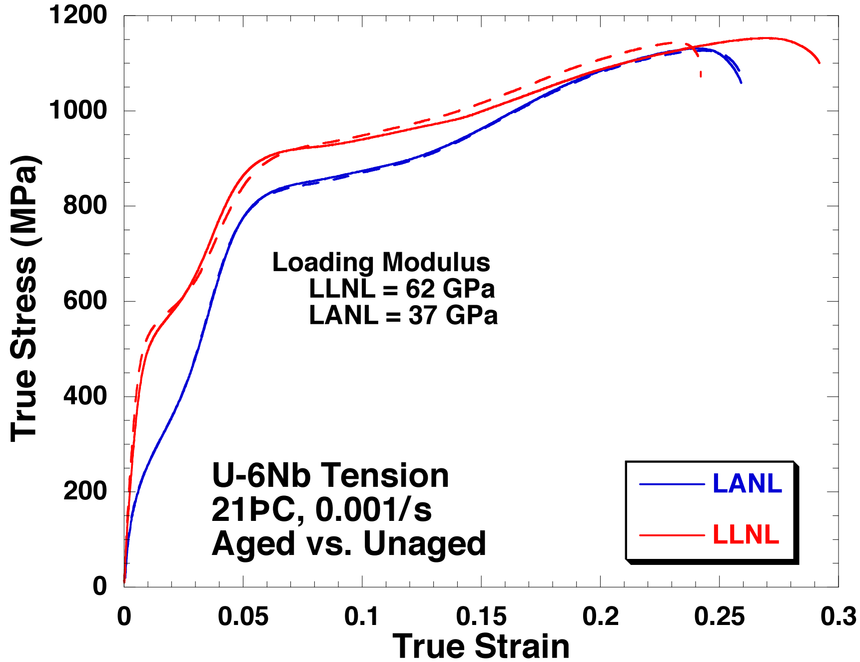
Next-generation solar cell architecture

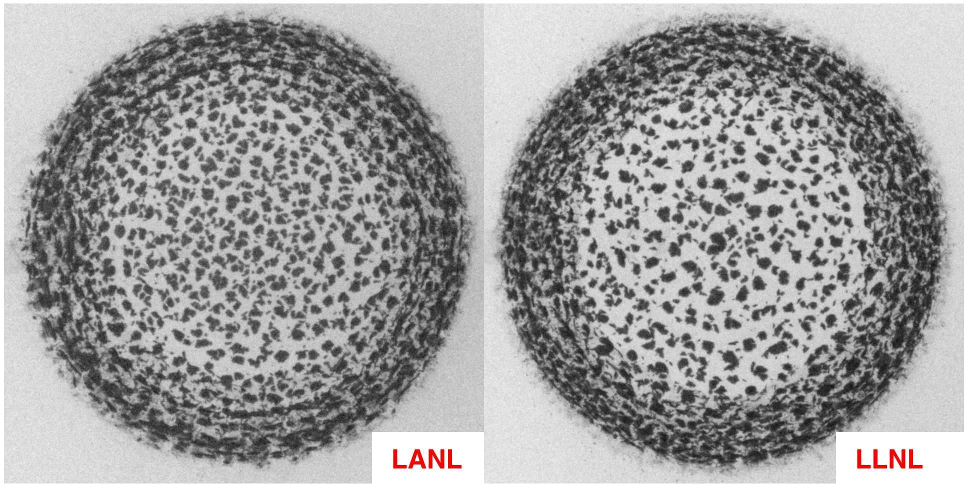
*Understanding and Controlling the Complexity of Real Materials*

# Mechanical behavior and HE-driven fragmentation of U-6%Nb show strong influence of metallurgical state

LANL = Solution treated / Quenched

LLNL = Solution treated / Quenched + Aged



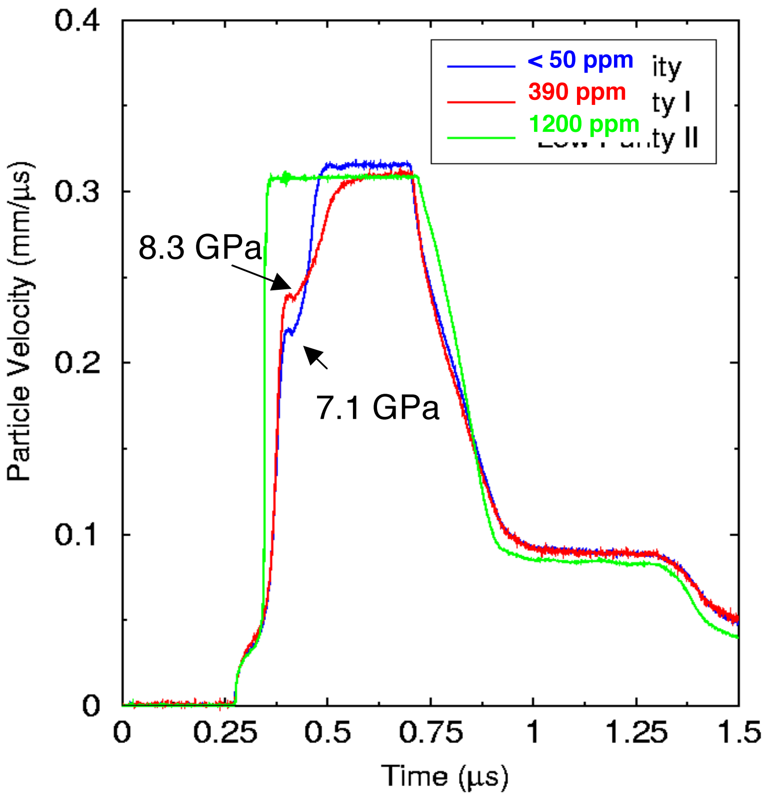



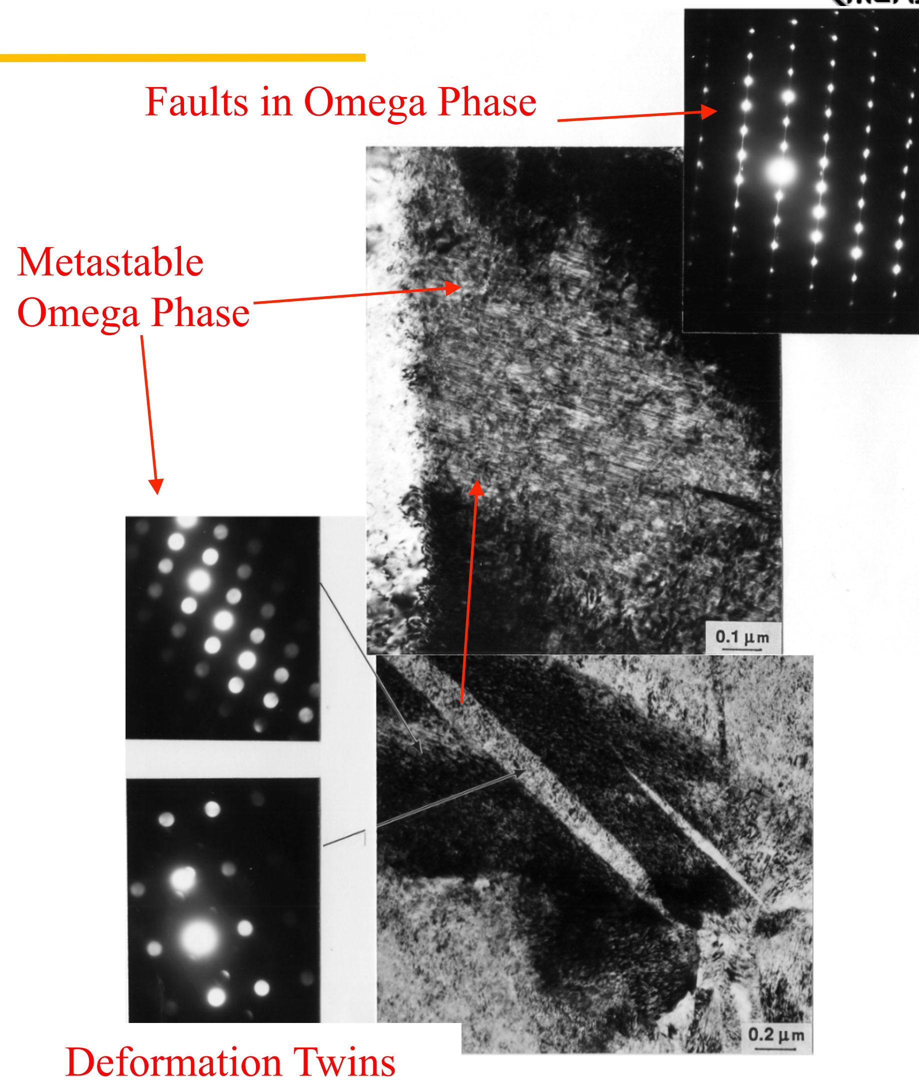

Quantitative analysis reveals 6σ difference in open area between images

*Process-aware understanding of materials performance is lacking*

# Shock-induced phase transitions reveal spatially complex processes with strong materials sensitivities

**Oxygen content suppresses the α−ω phase transition in Zr**

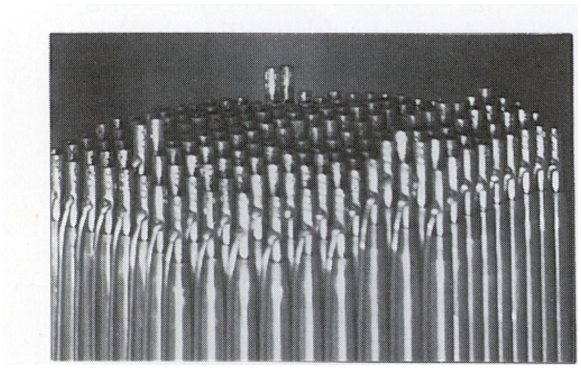


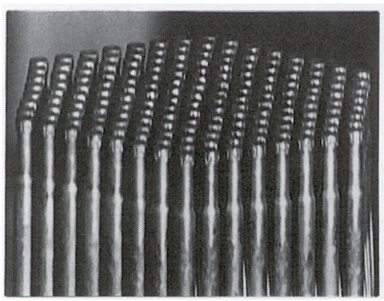

*Predictive models must acknowledge that solids are an assembly of crystals that deform according to their local state of stress*

# Radiation-resistant materials have tended to be developed serendipitously and empirically

- **Ferritic/martensitic steels (like HT9) are leading candidates for cladding, structural materials of fast breeder reactors (FBRs) and the first walls and blankets in conceptual fusion reactor designs**
- **They show resistance to void swelling and have adequate mechanical properties at elevated temperatures → expanded operating environments**

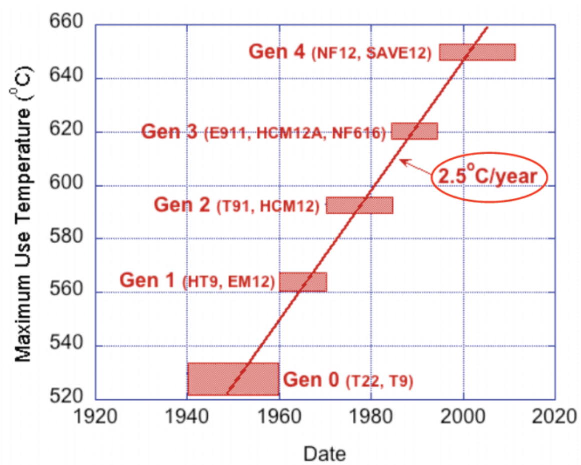


D9 irradiated to 2.1 $10^{23}$ (E>0.1MeV)*



HT9 irradiated to 1.9 $10^{23}$ (E>0.1MeV)*

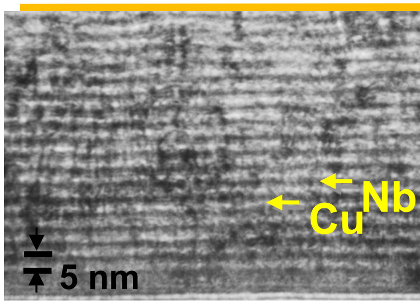
* Makenas et al 1990




after Zinkle, Busby Mater. Today 12 (2009) 12

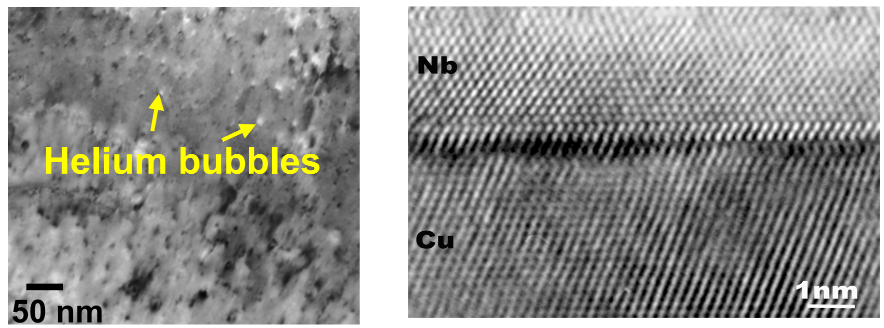
*However, our understanding of the atomic-level processes that control bulk behavior is substantially incomplete*

# Frontiers of materials discovery: Interface/structure manipulation produces enhanced strength and radiation resistance



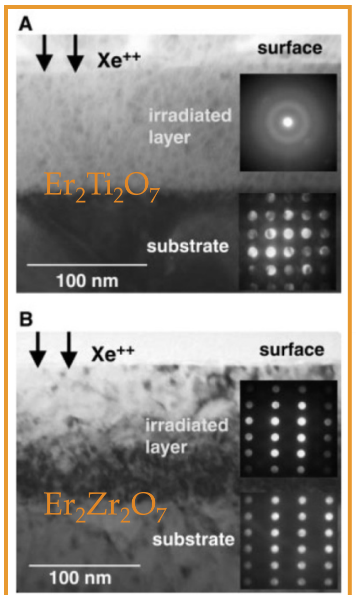

Nanolayer architectures produce materials strength that exceeds theoretical “limits”

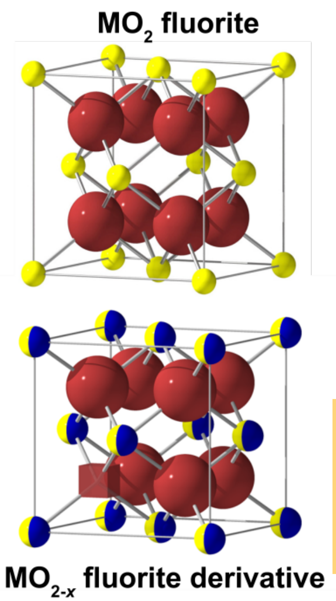
Same structures produce extreme radiation resistance by actively eliminating point defects




Pure Cu

5 nm layer thickness Cu-Nb multilayer

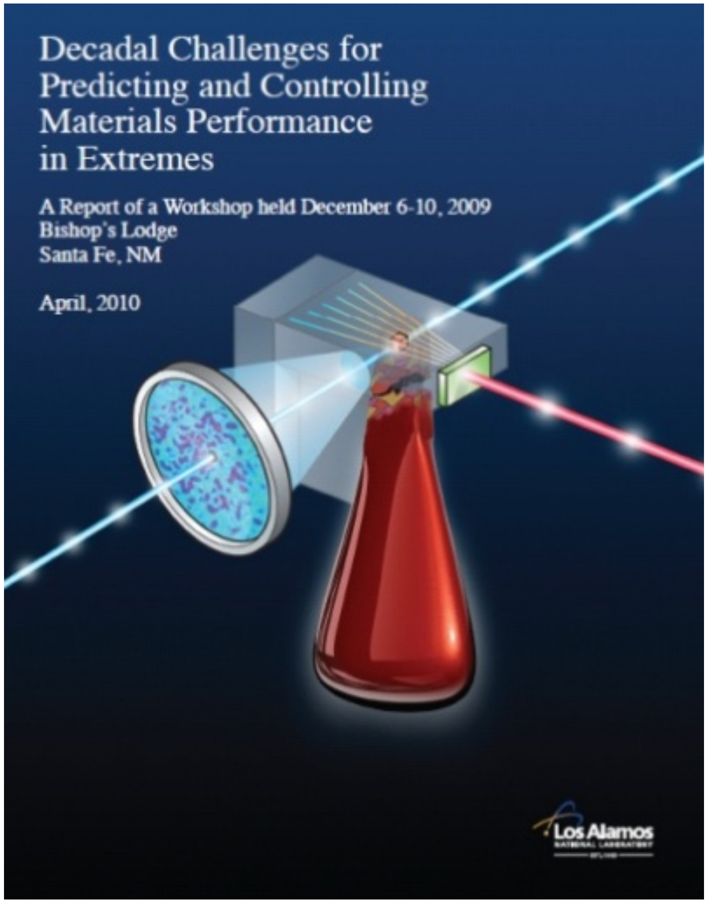



← Challenge is to translate these insights to bulk systems

*Can we discover ‘by design’ bulk materials that embody these principles and observe and manipulate their defect structures in ‘real’ deformation and irradiation extremes?*

# Materials research is on the brink of a new era of science in which the traditional approach of observation & validation of performance is replaced by prediction & control of materials functionality




**MaRIE builds on unique LANL capabilities to provide unique experimental tools needed to realize this vision:**

**In situ, dynamic measurements of real materials**

*Scattering & imaging simultaneously*

**in extreme environments**

*Dynamic & irradiation extremes*

**coupled to directed synthesis via predictive theory**

*Materials design & discovery*

# MaRIE builds on the LANSCE facility to provide unique experimental tools to meet this need

First x-ray scattering capability at high energy and high repetition frequency with simultaneous charged particle dynamic imaging

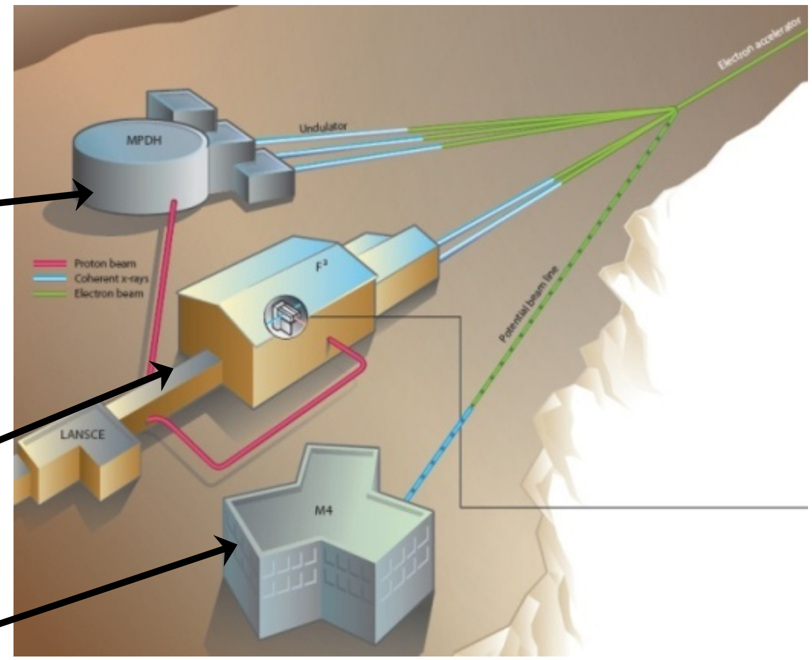
(**MPDH**: Multi-Probe Diagnostic Hall)

Unique in-situ diagnostics and irradiation environments beyond best planned facilities

(**F$^3$**: Fission and Fusion Materials Facility)

Comprehensive, integrated resource for materials synthesis and control, with national security infrastructure

(**M4**: Making, Measuring & Modeling Materials Facility)

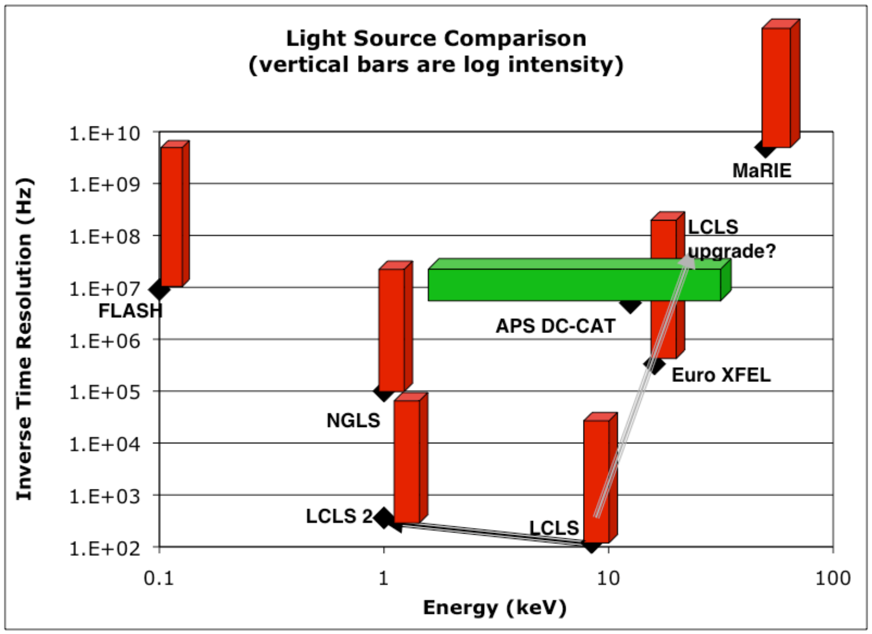



Unique very hard x-ray XFEL
Unique simultaneous photon-proton imaging measurements
Unique spallation neutron-based irradiation capability
Unique in-situ, transient radiation damage measurements
Unique materials design and discovery capability

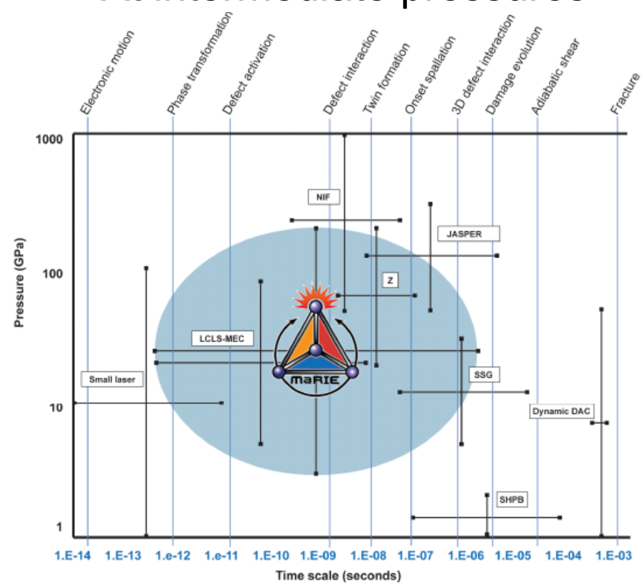
*MaRIE will provide unprecedented international user resources*

# **Through Multi-Probe Diagnostic Hall, MaRIE** provides unique scattering and imaging capabilities to bridge the micron gap in extreme environments

A high-energy-photon (50-115 keV) XFEL allows multigranular sample penetration and multipulse dynamics without significant sample perturbation

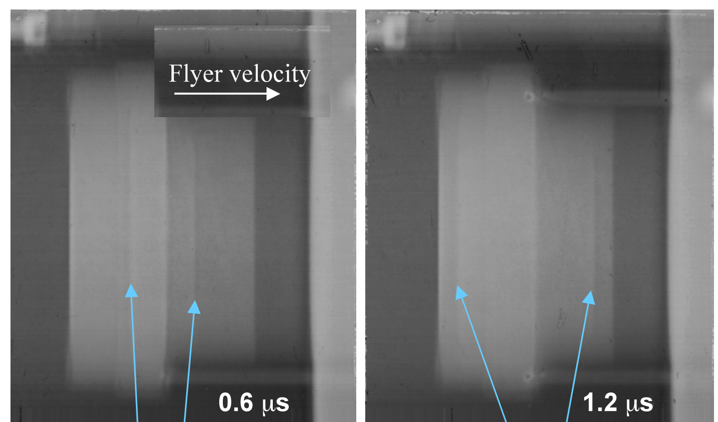



At intermediate pressures




Meanwhile, proton microscopy can provide absolute density & velocities through the sample volume

(pRad absolute Density: ~1%)

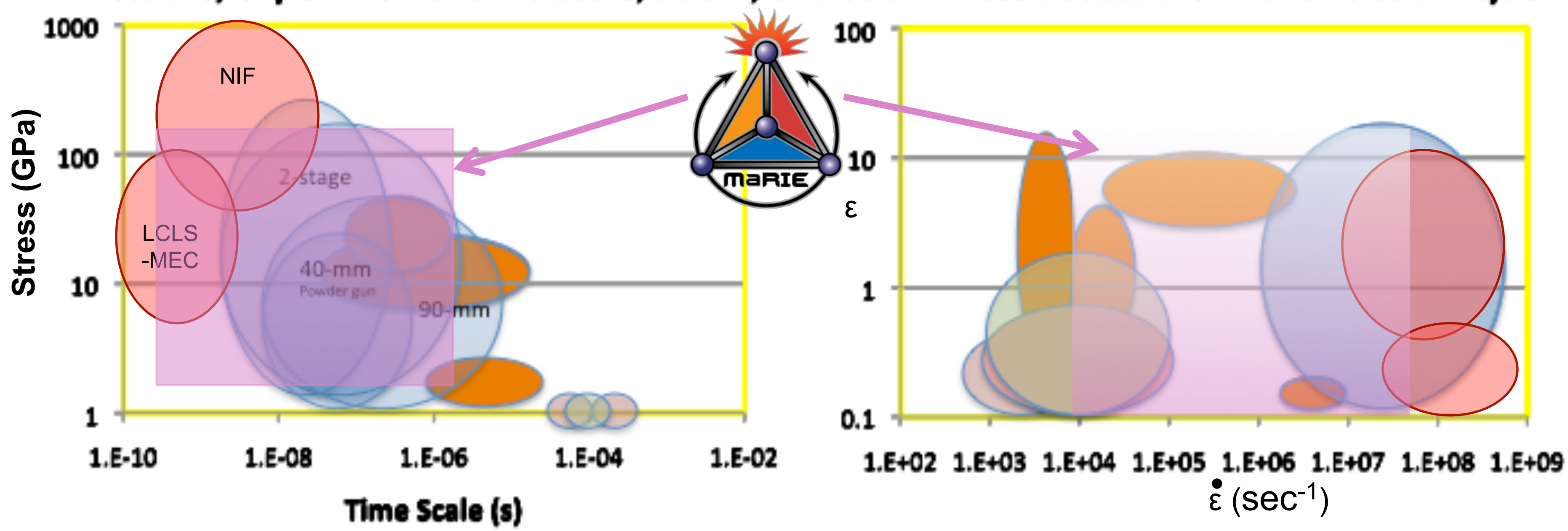



Shock Front

Shock Front

# We are further evaluating scientific requirements on dynamic (and static) extremes needed for the science

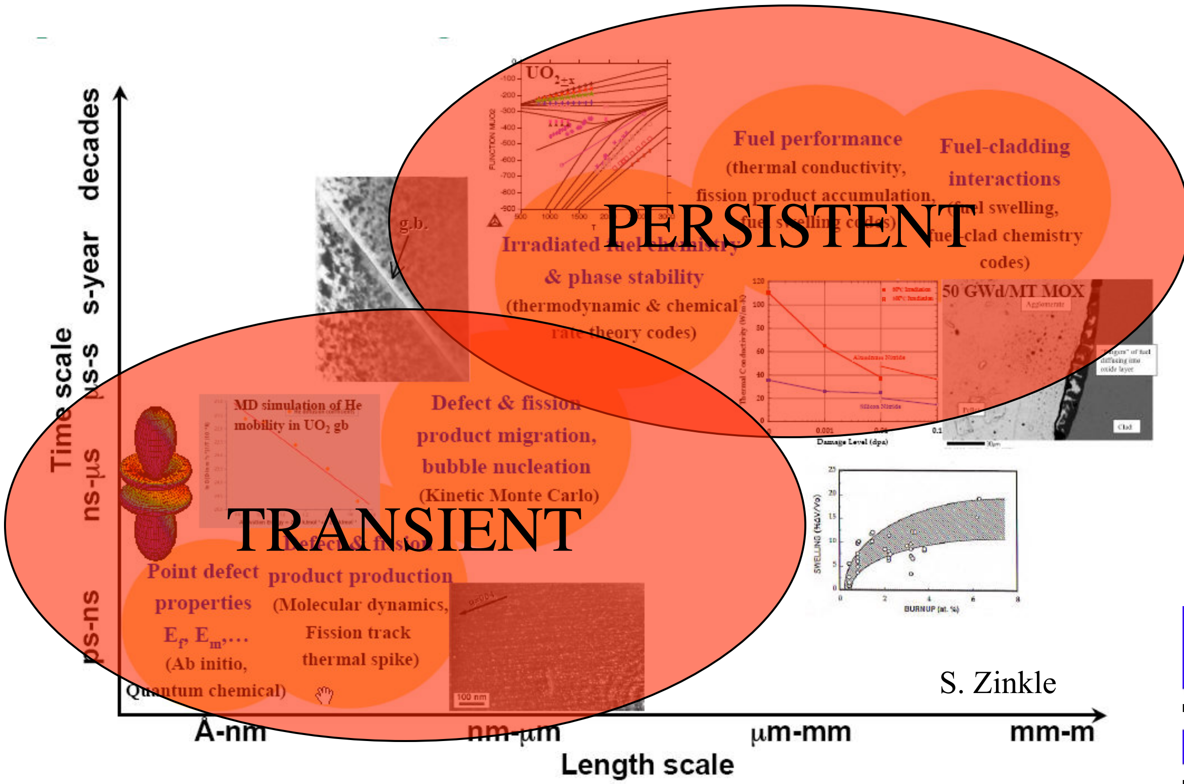
**Pressure, experimental time scale, strain, and strain rates accessible with this technique:**



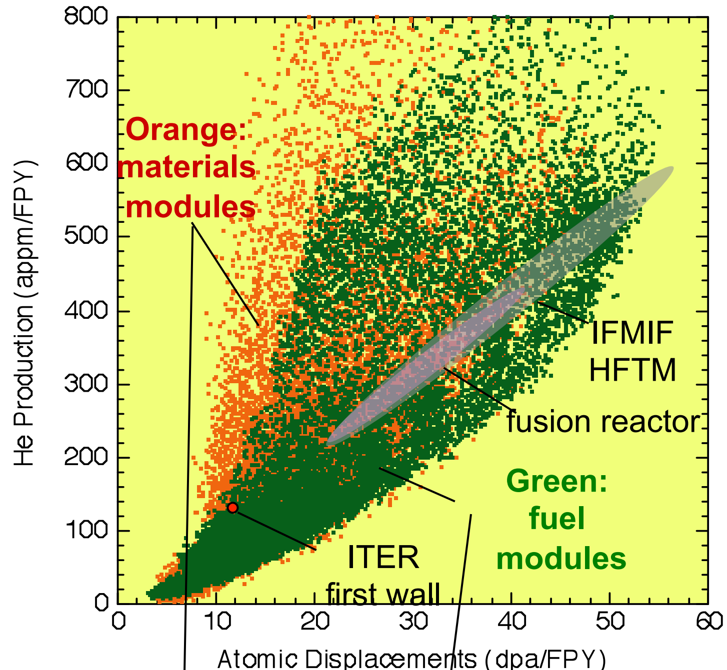

**Summary developed by Science Campaign 2 on stress, time, and strain and strain rate regimes of present techniques**

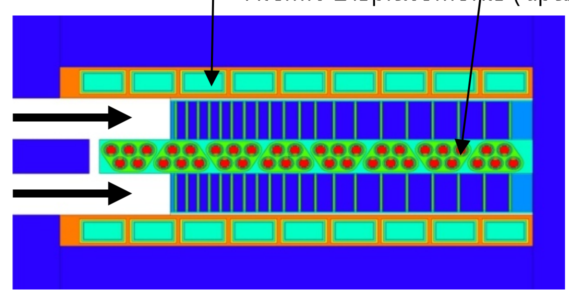
## **Through Fission Fusion Materials Facility, MaRIE** creates extreme radiation fluxes and advances the frontiers of radiation damage science through in situ measurements

The same x-rays (protons) enable in-situ (near in-situ) measurements…



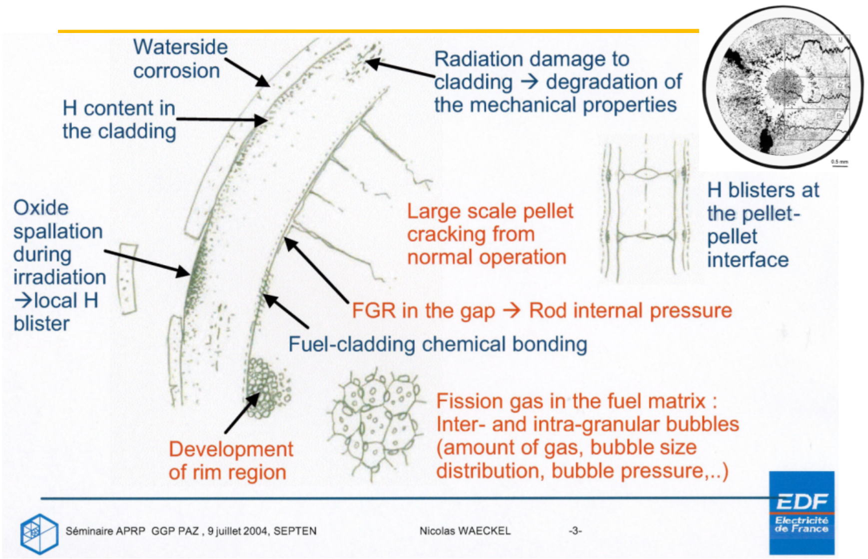

…in relevant environments



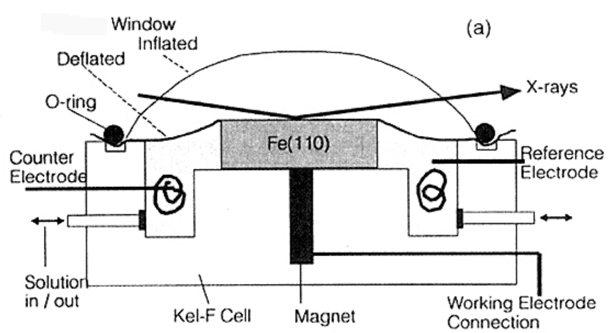



**MTS target assembly**

# For **some** key phenomena, ***in situ measurements*** in a neutron environment are essential for achieving a predictive understanding




**Monitor changes in fuels**



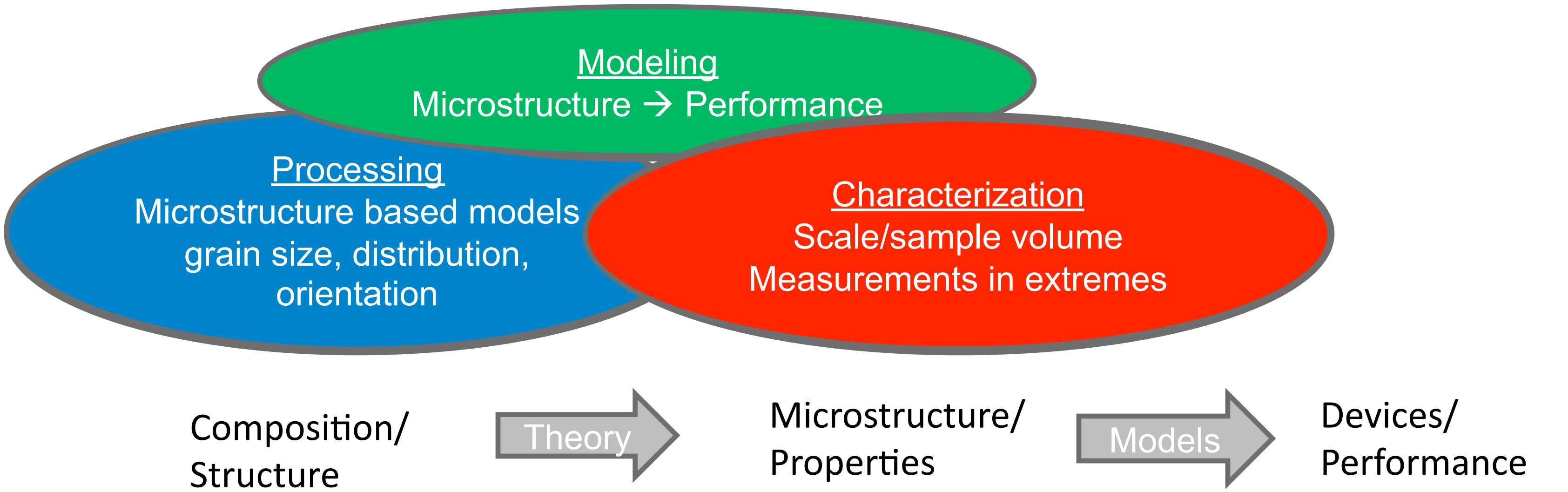

**Monitor corrosion conditions**

**For example,**

- **Transient aspects of irradiation assisted stress corrosion cracking**
- **Corrosion under different coolants, higher temperatures and fluxes**
- **Transient changes of micro-structure and stress under irradiation (e.g. creep)**
- **Custom tests for model validation**
- **Transient safety tests**
- **Short duration low-burn up data**
- **Active temperature control tests**

# Making, Measuring, Modeling Materials (M4): Accelerating complex materials design and discovery requires integration

## Process Aware Materials Performance

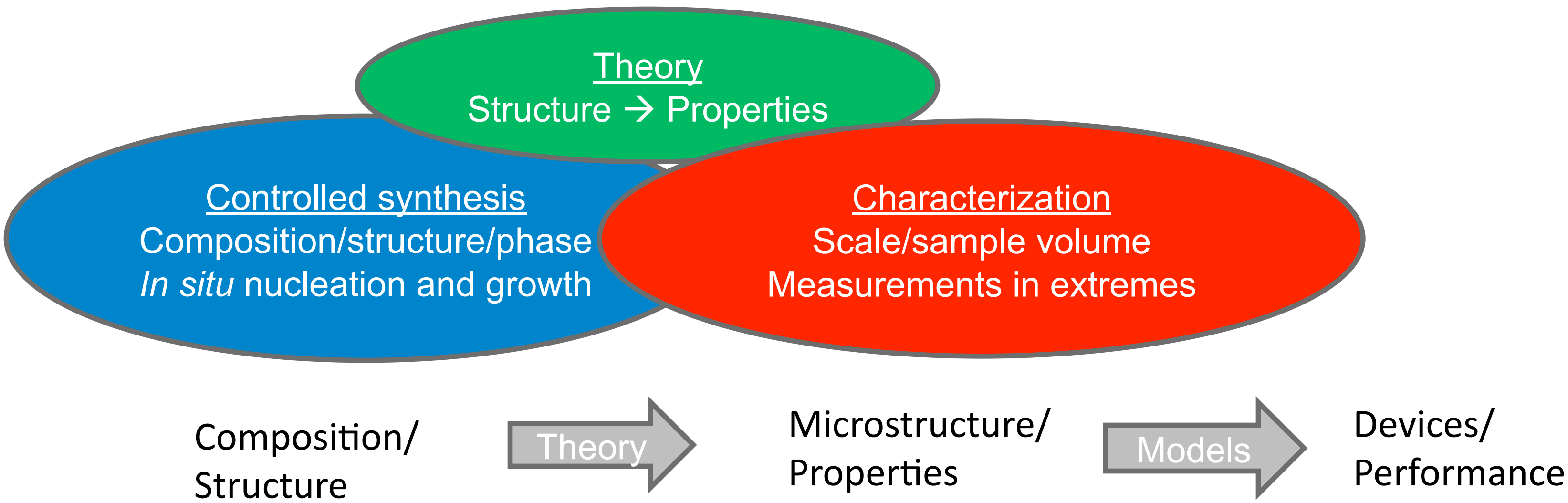



“Physicists perform elegant experiments on crummy samples while materials scientists perform crummy experiments on elegant samples”

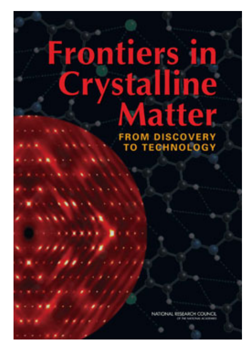
-Sig Hecker
Former LANL Director
(materials scientist)

# Making, Measuring, Modeling Materials (M4): Accelerating complex materials design and discovery requires integration

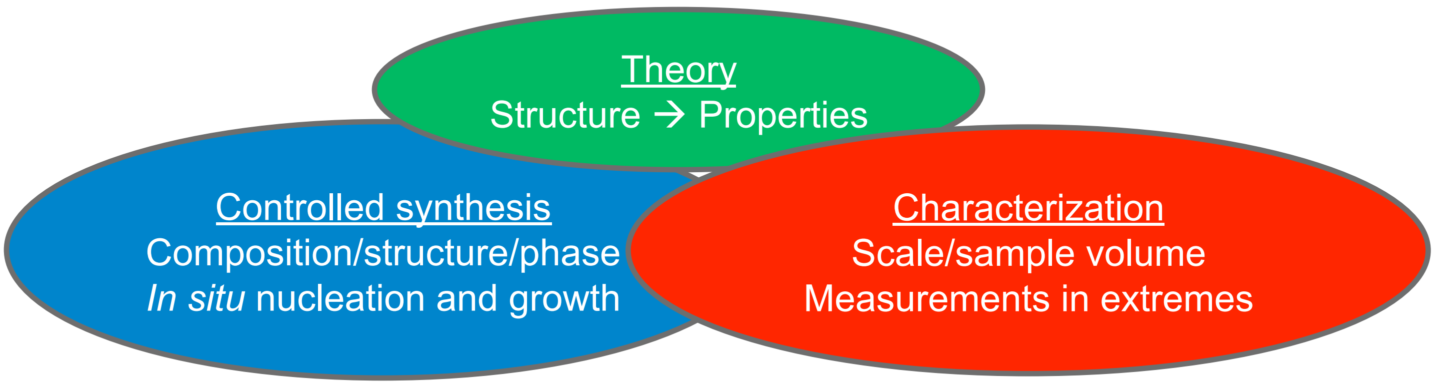
## Materials Discovery




. *"A **systematic, highly coordinated research effort** in which **synthesis is strongly coordinated with modeling and the characterization of novel materials with controlled … structures**, tailored surface functionality, and nanostructured architectures is **critically needed**"*

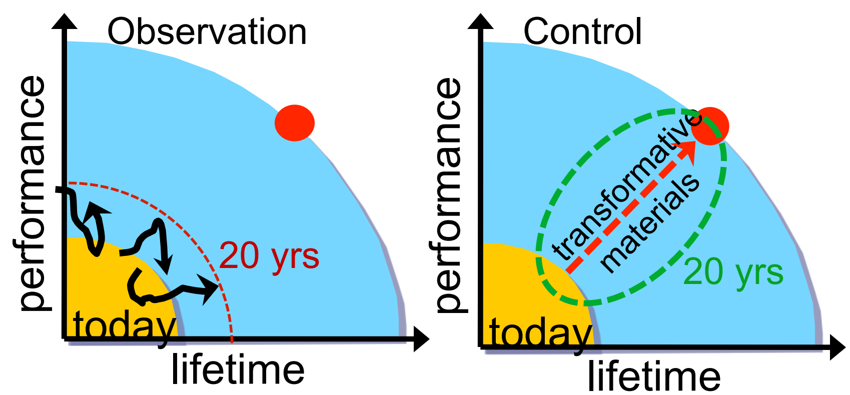


# Making, Measuring, Modeling Materials (M4): Accelerating complex materials design and discovery requires integration

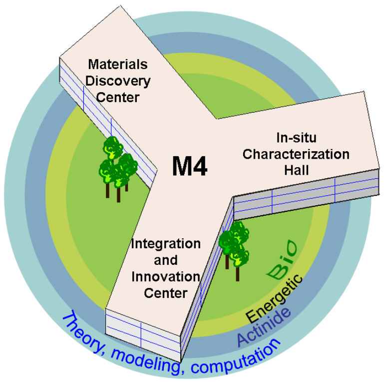


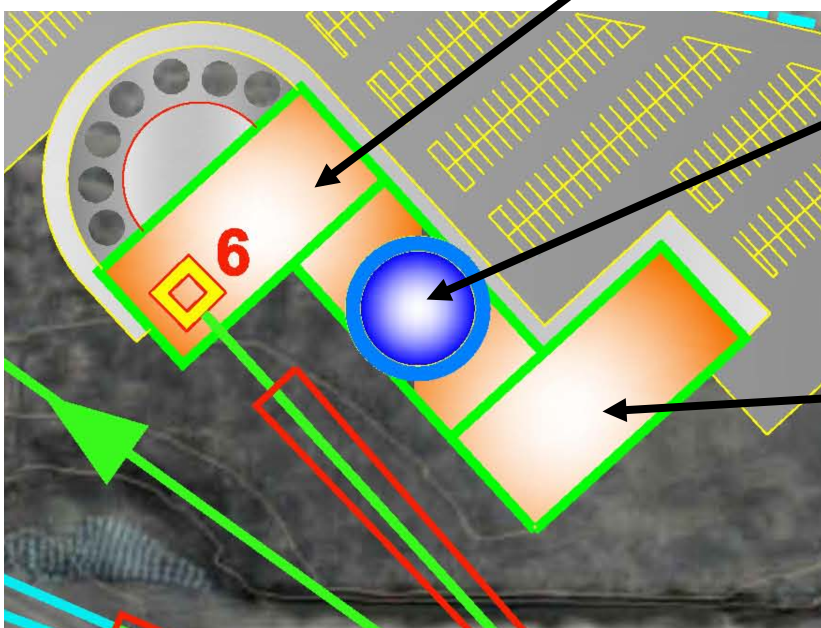


We must move from
structure → property paradigm
To a new paradigm of
function → structure



# **Through M4 Facility, MaRIE** provides the directed synthesis of materials essential for defect/interface control and materials discovery




M4 XFEL end station
- Other Extremes (E,H, pH)
- In situ synthesis probes

User Gateway
- Co-design Center
- Visualization Capability

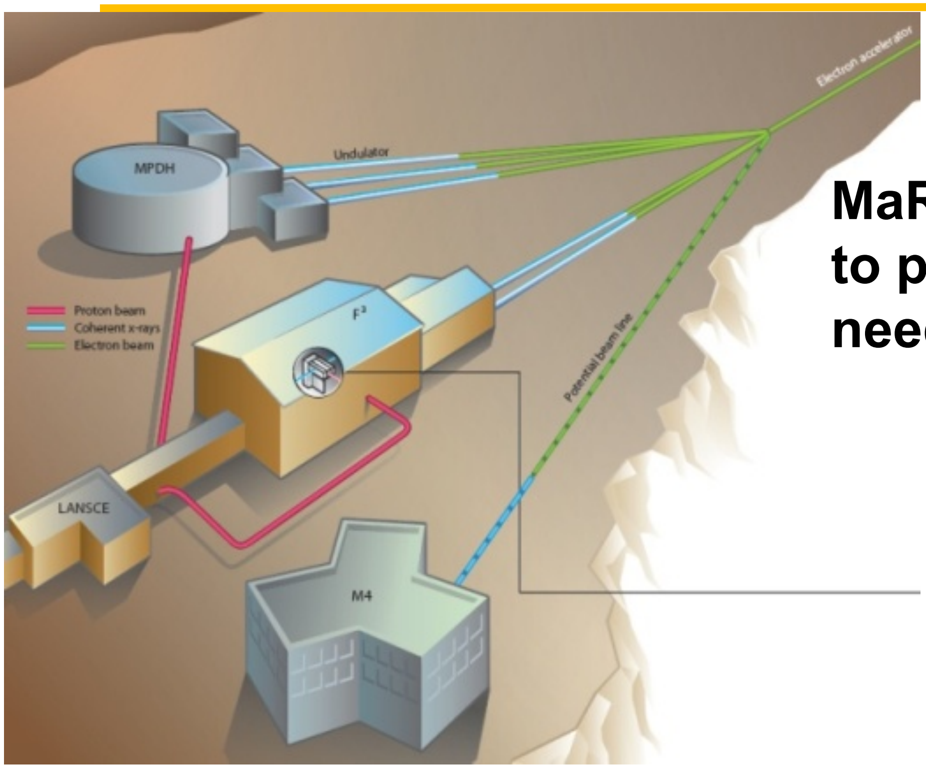
Multi-scale Synthesis & Crystal Growth
- Characterization
- National Security Infrastructure

# MaRIE photon needs can be met by an XFEL that is technically feasible and affordable

| | MPDH | FFF | | M4 | |
|---|---|---|---|---|---|
| Energy/Range (keV) | 50 | 50 | 50-600 | < 5 | 5-50 |
| Photons per image | $10^{11}$ | $10^{11}$ | $10^{9}$ | $10^{9}$ | $10^{11}$ |
| Time scale for single image | 50 fs | >1 s | 0.001 s | 50-500 fs | 50 fs |
| Energy Bandwidth ($\Delta$E/E) | $10^{-4}$ | $10^{-4}$ | $10^{-3}$ | $10^{-4}$ | $10^{-4}$ |
| Beam divergence | 1 $\mu$rad | 1 $\mu$rad | < 10 $\mu$rad | < 10 $\mu$rad | 1 $\mu$rad |
| Trans. coherence (TC) or spatial res. | TC | TC | 1-100 $\mu$m | TC | TC |
| Single pulse # of images/duration | 100/1.5 $\mu$s | - | - | - | - |
| Multiple pulse rep. rate/duration | 120 Hz/day | 0.01 Hz/mo. | 0.01 Hz/mo. | 1 KHz/day | 0.01 Hz/days |
| Longitudinal coherence | yes | yes | no | no | yes |
| Polarization | linear | linear | no | Linear/circular | linear |
| Tunability in energy ($\Delta$E/E/time) | 2%/pulse | fixed | fixed | 10%/s | 10x/day |

- Photon energy - set by gr/cm$^2$ of sample and atomic number
- Photon number for an image - typically set by signal to noise in detector and size of detector
- Time scale for an image - fundamentally breaks down to transient phenomena, less than ps, and semi-steady state phenomena, seconds to months
- Bandwidth - set by resolution requirements in diffraction and/or imaging
- Beam divergence - set by photon number loss due to stand-off of source/detector or resolution loss in diffraction
- Source transverse size/transverse coherence - the source spot size will set the transverse spatial resolution, if transversely coherent then this limitation is not applicable so transverse coherence can be traded off with source spot size and photon number
- Number of images/rep rate/duration – images needed for single shot experiments/image rep rate/ duration of experiment on sample
- Repetition rate - how often full images are required
- Longitudinal coherence – 3D imaging
- Polarization - required for some measurements
- Tunability – time required to change the photon energy a fixed percentage

# MaRIE will be the first capability with unique co-located tools necessary to realize transformational advances in materials performance in extremes




**MaRIE builds on unique LANL capabilities to provide unique experimental tools needed to realize this vision:**

**In situ, dynamic measurements of real materials**

*Scattering & imaging simultaneously*

**in extreme environments**

*Dynamic & irradiation extremes*

**coupled to directed synthesis via predictive theory**

*Materials design & discovery*

# Science-driven Requirements Lead to Integrated Facility Needs Fulfilled by MaRIE

**User Driven Science** — Materiel Needs — **Functional Requirements** — Alternatives Analyses — **Performance Gaps** — Preferred Alternative & Roadmap — **Facility Concept**

## User Driven Science

### Dynamic Extremes
- Microstructure Evolution
- Stochastic Explosive Microstructure & Detonation
- Fluid/Mineral Interactions in
- 3-D Measurements of Turbulent

### Radiation Extremes
- Irradiation Stability of Structural Nanocomposites
- Fission Gas Bubble & Swelling in $UO_2$ Nuclear Fuel
- Mechanical Testing of Structural Mateials in Fusion/Fission Environ.
- Measurements of Temperature, Microstructure & Thermal Transport
- Rad Damage in Passive Oxide Films & its Influence on Corrosion

### Control of Complex Materials & Processes
- Understanding Emergent Phenomena in Complex Materials
- Developing Practical Superconductors by Design

### Energy Conversion & Storage
- Achieving Practical High-Density Energy Storage Through New Support/Catalyst Electrode Systems
- Solar Energy Conversion w/ Fun-ctionally Integrated Nanostructures

### Process-Aware Materials Performance
- Nanostructured Ferritic Alloys
- Exploring Separate Effects in Pu

## Functional Requirements

### Environments
- Dynamic pressure <200 GPa
- Strain rate = $10^1$–$10^7$ $s^{-1}$
- Temperature = 77–2000 K
- High Explosives < 30 g
- Pu isotope samples < 3 mm thick
- Irradiation rate < 35 dpa/fpy
- He(appm)/dpa ratios: 0.1-1, 9-13
- Irrad Volume: 0.5 l @ >14 dpa/yr

### Measurements
- Scattering
  - Defects: 1 nm res over 10 um
  - Stress: 1-2 um res over 100 mm
  - Lattice Strain: 10 nm res in 3D
- Density Imaging
  - 0.1-1 nm, <1-ps res over 10 $\mu$m
  - 10 nm, <1-ps over 50 $\mu$m
  - 0.1-1 um, < 0.3 ns over 0.1-1 mm
- Spectroscopic
  - 3D chemistry mapping w/ 1$\mu$m res
- Themo-Physical Measurements
  - Temperature: 1 $\mu$m res
  - Thermal Conductivity w/ 1 mW/m-K res

### Synthesis with Characterization
- Organic, inorganic, biomaterials incl nanomaterials, HE & actinides
- Thin films with buried interface characterization

## Performance Gaps

**50 keV coherent x-ray source with $10^{11}$ photons per macropulse focused to 1-200 $\mu$m**

**Dynamic charged particle imaging with 20-GeV electrons**

**Tunable ultrashort x-ray source for excitation: 5-35 keV, 100 fs, focused to 10 nm**

**Ultra short pulse lasers for spectroscopy: THz (2 meV) to VUV (6 eV)**

**MW fast neutron source with $2x10^{15}$ n/cm2-s and >4000 h/yr operation with < 10 beam trips per day over 1 min**

**Crystal growth with control of impurities & defects during and after fab**

**Deposition Lab w/CVD, PVD, evaporation, ion beams**

**Nanofabricaiton Lab w/ lithography, dry & wet etch, thermal processing**

**Characterization Lab w/ SEM, FE-SEM, AFM, SALVE, ion beams**

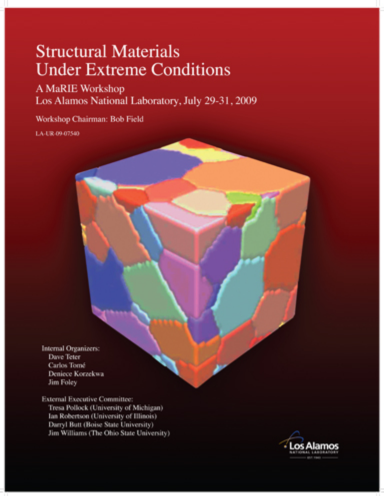
**Data Visualization Lab w/ 1MB-10TB available per expt.**

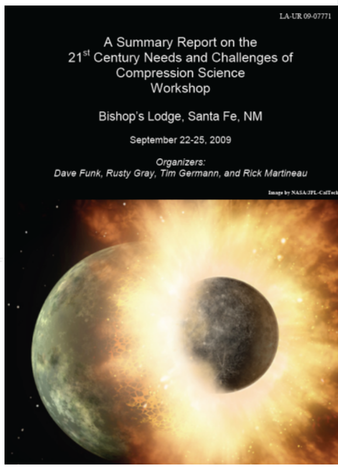
## Facility Concept

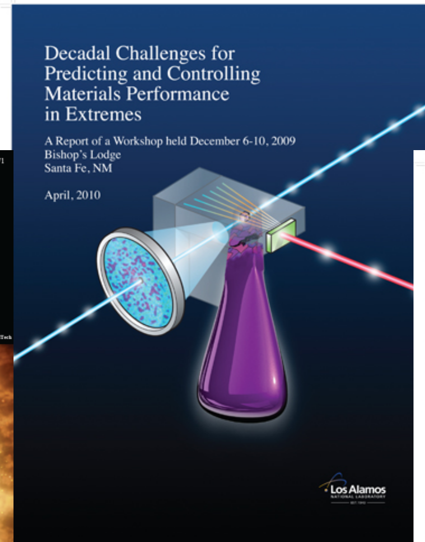
MaRIE builds upon existing $B investments at LANSCE with the addition of the:

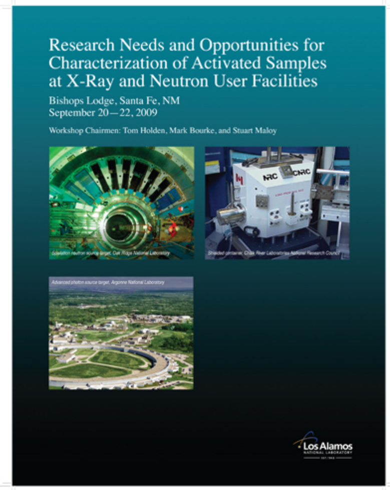
- Electron Linac with XFEL Systems
- Multiprobe Diagnostic Hall
- Fission-Fusion Materials Facility
- Making, Measuring, & Modeling Material Facility

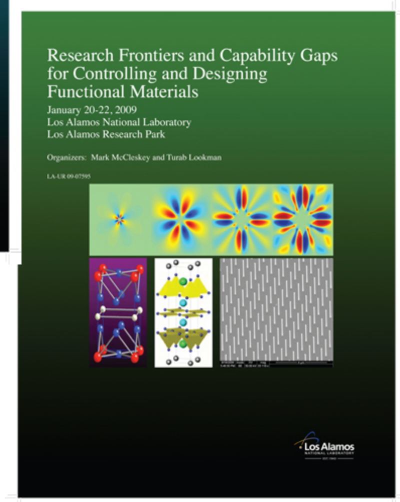
# Community-based workshops have helped to define the decadal challenges for predicting and controlling materials performance in extremes



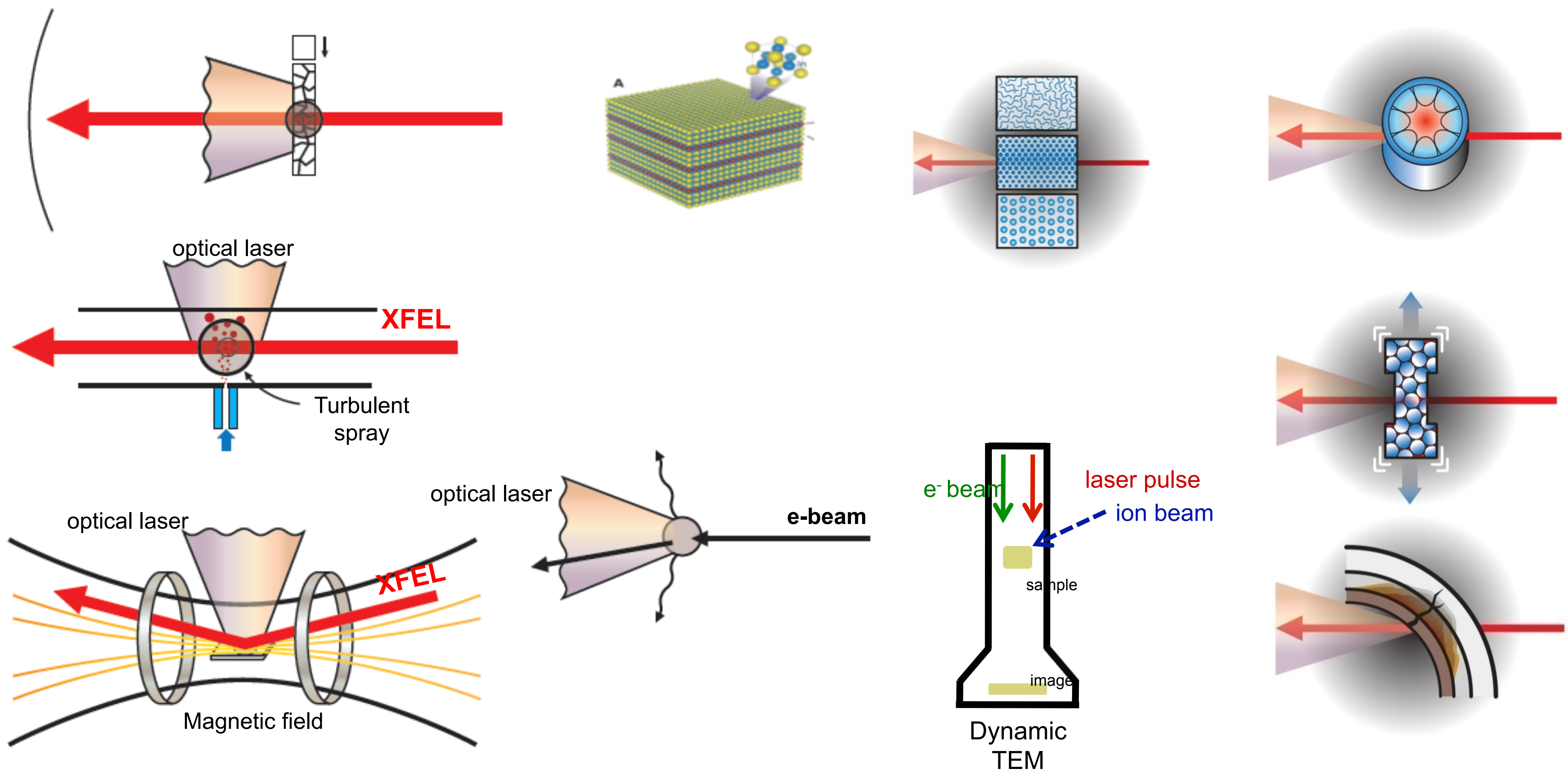




http://www.lanl.gov/source/projects/marie/workshops.shtml

# First experiment teams include ~170 scientists from ~ 60 institutions in 10 countries

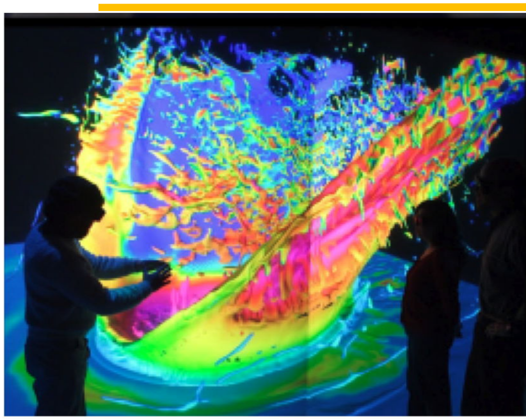


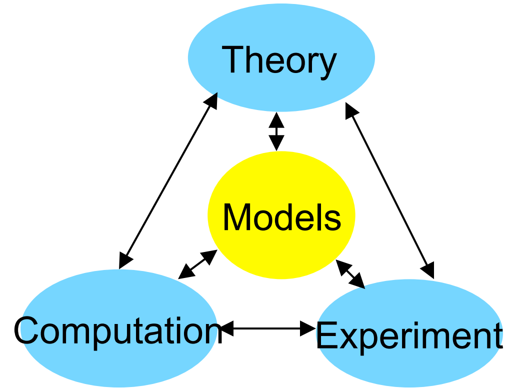

*We're laying the foundation for a robust MaRIE user community*

# MaRIE will address problems central to Department of Energy missions in energy, science, and security

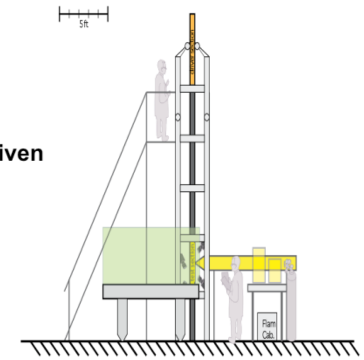
- What are the consequences of materials failure for weapons performance?
- How do we accelerate the certification of materials to enable a nuclear renaissance?
- Can we predict and prevent materials damage?
- Can we discover by design materials to perform in unprecedented irradiation extremes?
- How do we predict and control microstructure for designed materials performance?
- Can we design and synthesize new materials with controlled functionality?

# Developing predictive capability across all relevant scales for turbulent flows, including those with "strength"

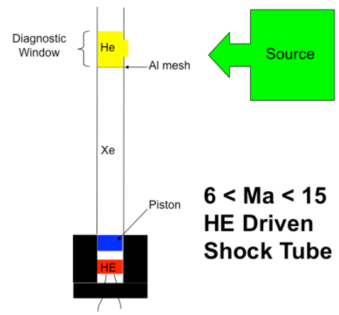




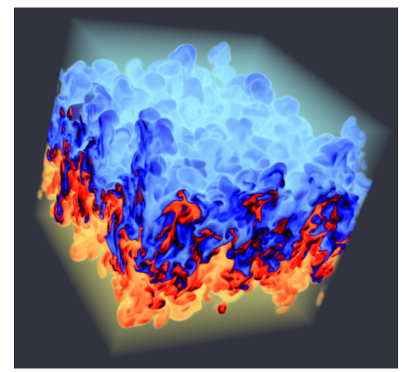

<u>The goal</u> :- Develop predictive capability for turbulent mix



**0 < Ma < 6**
**Pressure Driven Shock Tube**




**6 < Ma < 15**
**HE Driven Shock Tube**

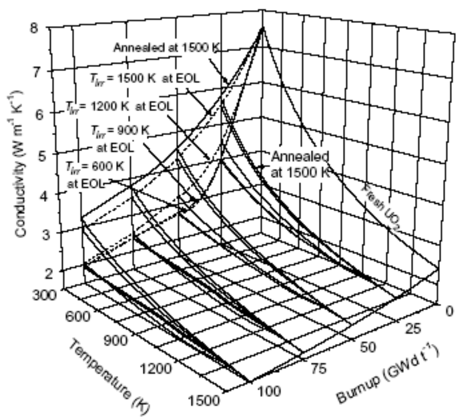


<u>The model</u> :-Direct Numerical Simulation coupled to Reynolds-Averaged Navier Stokes turbulence model

<u>The first experiment</u> :-***Multi-scale fluid dynamics experiments with the ability to measure turbulent flows at all relevant space and time scales (μm and μsec), featuring opaque materials and/or high-velocity flows requiring high repetition measurements.***

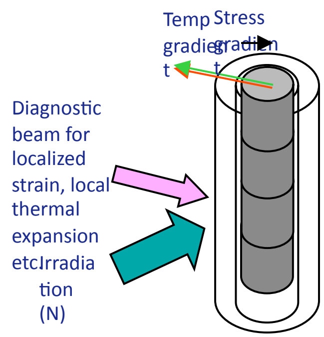
**Team includes:** Malcolm Andrews et al. (LANL, UK AWE, Texas, Johns Hopkins, …)

# Determining spatially resolved thermophysical properties in prototype fuel geometries

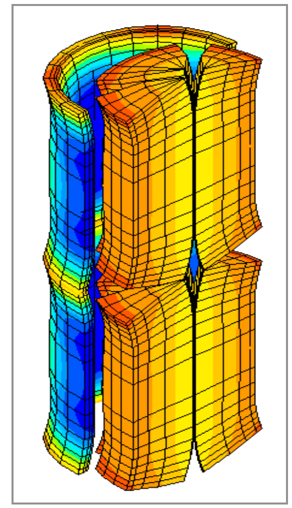



Predicted and measured UO2 thermal conductivity

**<u>Goal</u> :- Spatially resolved predictions and measurements of engineering performance of prototype fuel pin geometries as a function of power, burnup and time**




**<u>Experiment</u> :- MaRIE will use photons, (electrons & neutrons) to make unique measurements of phase, strain, microstructure, porosity & temperature distributions on engineering scale samples in & out of a radiation environment**

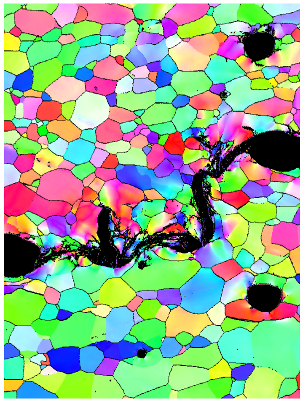


(PLEIADES code, CEA, France)

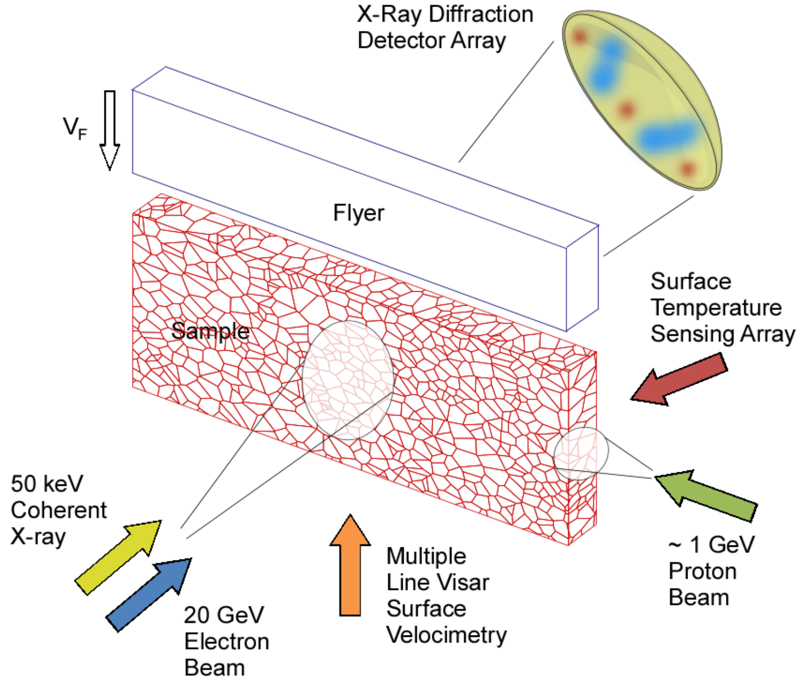
**<u>Model</u> :- Stress/ Temperature Field in a Fuel Element consisting of two ceramic pellets and metallic clad.**

**Team includes:** Marius Stan et al. (LANL, ANL, Wisconsin, INL, CEA …)

# Understanding the role of microstructure-based heterogeneity evolution in material damage




**The goal :- Predict dynamic microstructure and damage evolution**

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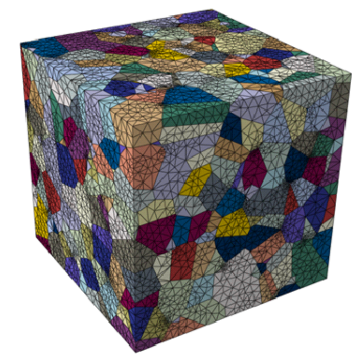
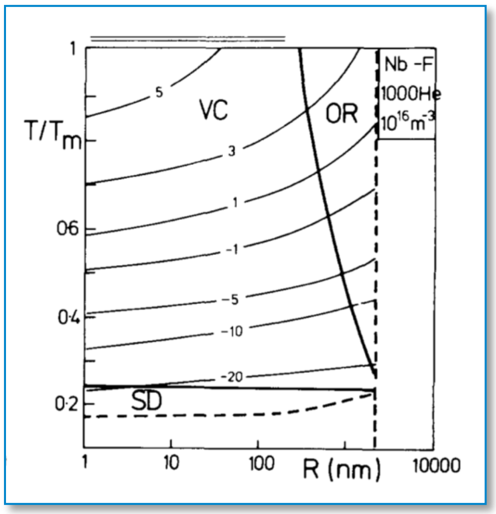

Meso-Scale Theory and Simulation

**The first experiment :- Multiple, simultaneous dynamic in situ diagnostics with resolution at the scale of nucleation sites (< 1 μm; ps – ns)**

**The model :- Accurate sub-grain models of microstructure evolution coupled to molecular dynamics**

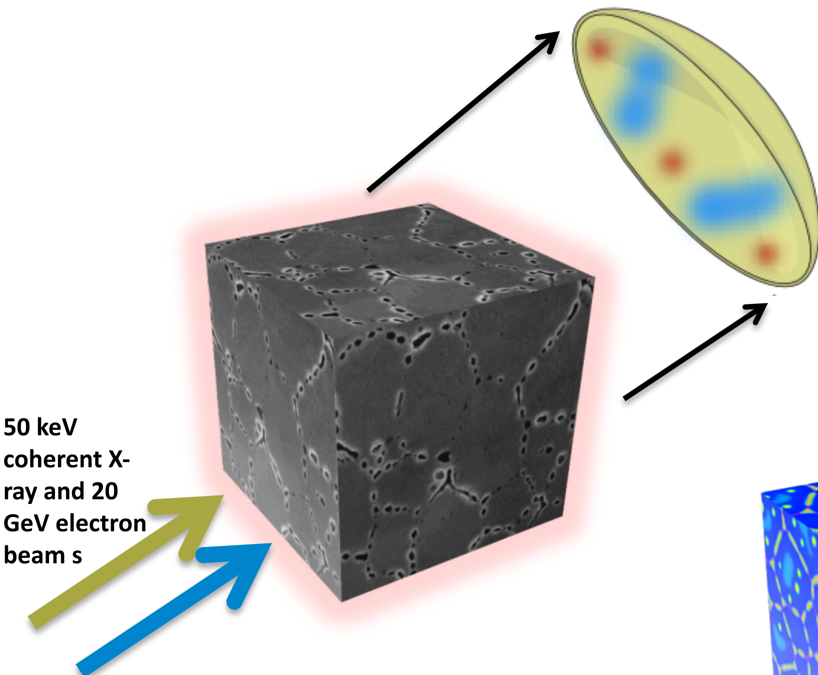
**Team includes:** Curt Bronkhorst et al. (LANL, UK AWE, BYU, CalTech, Ohio State, …)

# Understanding creep via transient measurements of cavity growth under fast neutron irradiation

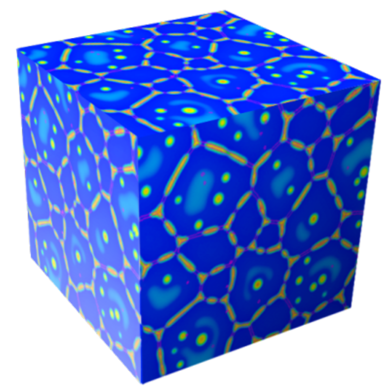



**<u>The goal</u> :- Predicted and measured cavity growth mechanism maps of creep under extreme irradiation conditions**

**50 keV coherent X-ray and 20 GeV electron beam s**



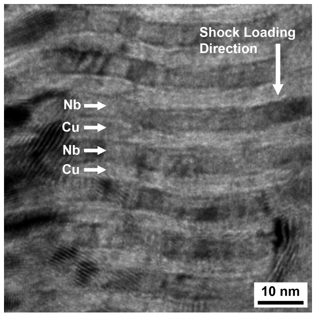
**<u>The first experiment</u> :- Transient imaging and scattering measurements of *mesoscale* objects with *nm spatial resolution* in an extreme radiation environment**



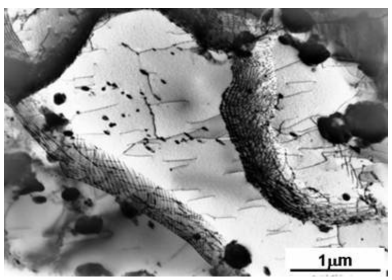
**<u>The model</u> :- Phase field simulation of heterogeneous nucleation of gas bubbles**

**Team includes:** Marius Stan et al. (LANL, ANL, Wisconsin, INL, CEA …)

## Understanding the role of interfaces in strain evolution

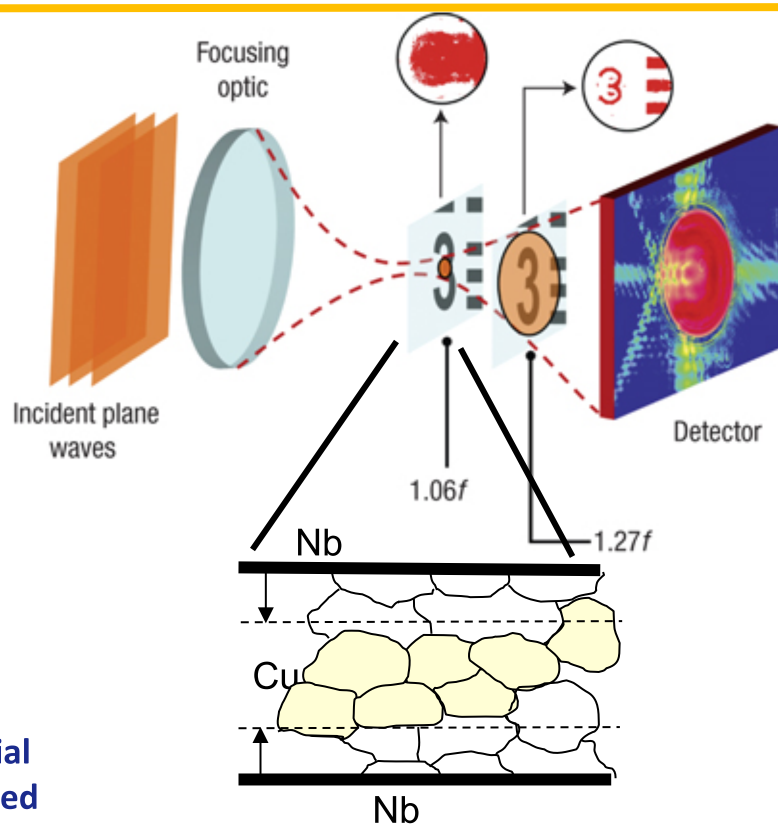



Nano laminates

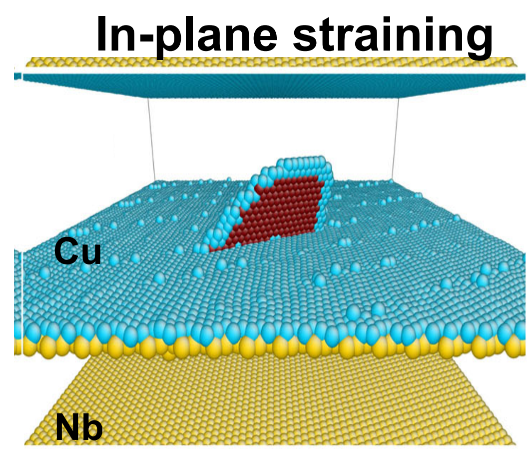



ODS steel

**The goal : Predict interfacial microstructure for increased strength and irradiation resistance**



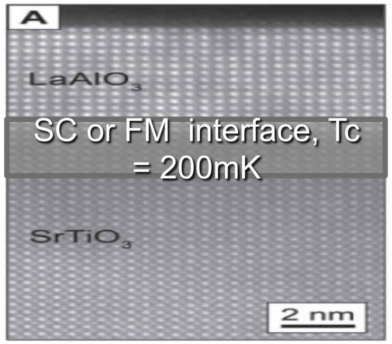

**The first experiment :**
**3-D movies of dislocation dynamics in materials at buried interfaces, micron field of view with focusing at nm resolution**

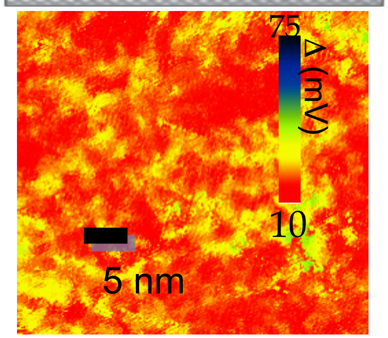



**The model :Advanced $M^2S$ with micron scale, multigranular predictions**

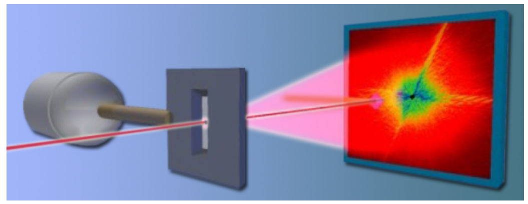
**Team includes:** Nate Mara et al. (LANL, ANL, CMU…)

# Understanding complex functionality beyond Bloch& Boltzmann

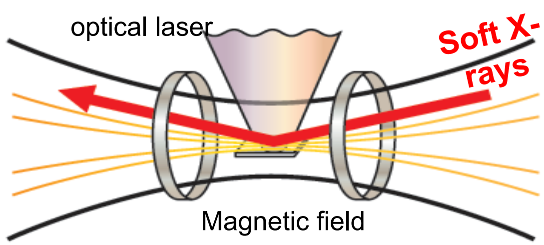



**The goal :- Predict and control functionality at interfaces with complex energy landscapes**

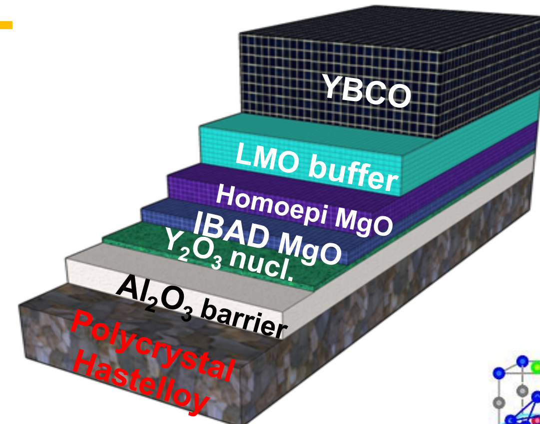


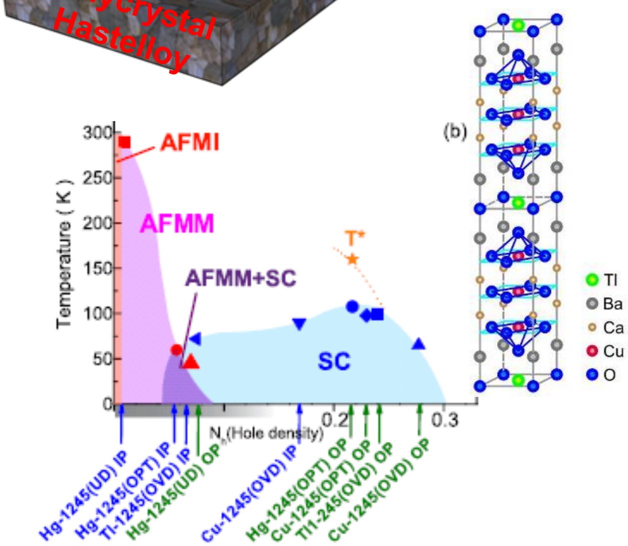
High energy diffraction




Soft energy electronic and magnetic infromation

**The first experiment**
**Visualization overlay and comparison of ultrafast 3-D imaging of structure using hard X-rays and ultrafast 3-D imaging of functionality with soft X-rays**

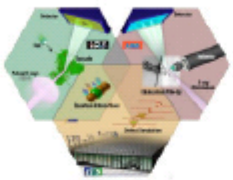



**The model : Beyond periodic repetition of structure (interfaces), beyond temporal limits of Boltzmann**

**Team includes:** Alp Findikoglu et al. (LANL, ANL, BNL,…)

# Recent efforts to integrate theory and experiment through co-design for materials in extremes are succeeding



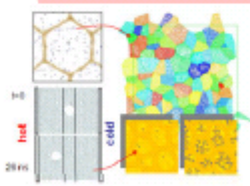
Center for Defect Physics

(ORNL)

EFRCs

CMIME

Center for Materials at Irradiation and Mechanical Extremes



Center for Materials Science of Nuclear Fuels

(INL)

LDRD-DR: Dennis-Koller

CASL

ExMatEx

LDRD-DR: Germann

LDRD-DR: Beyerlein

DOE “Blue Skies” Initiatives

*Materials in Extremes/Irradiation Resistant Materials (BES/FES/ASCR)/NNSA/NE*

*Exascale Computing - ASCR/NNSA*

OSTP: Computational Materials by Design for Innovation

Example: Peer facilities for accelerating certification and predicting damage

# Current capabilities enable collaborations, help refine MaRIE facility requirements, and enable science exploration

**Controlled Functionality; Process-Aware Certification; Transformational Performance**

**and BEYOND**

**DECADE**

*MPDH* *F^3* *M4*

**pRad @ GSI**
**LCLS-MEC**
**DC-CAT**
**MTS**
**HFIR, ATR**
**JANNuS**
**Nanocenters**
**Exascale Co-design**
**EFRCs**

**PRESENT**

***CAPABILITIES***

| p, e- imaging | X-ray Sources | Lasers, Drivers | In-Situ Measurements | Relevant Doses | Lab-Scale Extremes | In-Situ Char. | Synthesis Capability |
|---|---|---|---|---|---|---|---|

**Multi-Probe Measurements** | **Extreme Environments** | **Directed Synthesis** | **Integration (esp. theory)**

**Observation → Control**

# At LANSCE today, a flexible 1 MW, 800 MeV proton accelerator drives several user facilities

Unique, highly-flexible beam delivery to multiple facilities 6 mo/yr @ 24/7 with ~ 1200 user visits

**Lujan Center**

- *Materials science and condensed matter research*
- *Bio-science*
- *Nuclear physics*
- *A National BES user facility*

**WNR**

- *Nuclear physics*
- *Semiconductor irradiation*

**Ultra-cold Neutron Facility**

- *Fundamental nuclear physics*

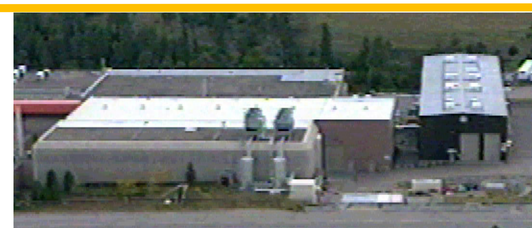
**Proton Radiography**

- *HE science, dynamic materials science, hydrodynamics*

**Isotope Production Facility**

- *Nuclear medicine*
- *Research isotope production*

# LANL National User Facilities form a synergistic triad for materials research



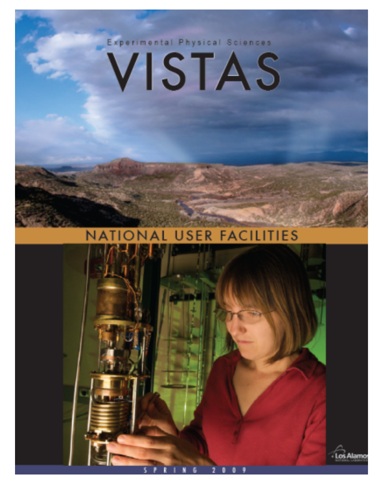
Nano-materials synthesis and characterization

Research with high magnetic fields

MATERIALS

LUJAN CENTER
Los Alamos Neutron Science Center
Los Alamos National Laboratory

Neutron scattering




http://www.lanl.gov/orgs/adeps/VISTAS/index.shtml

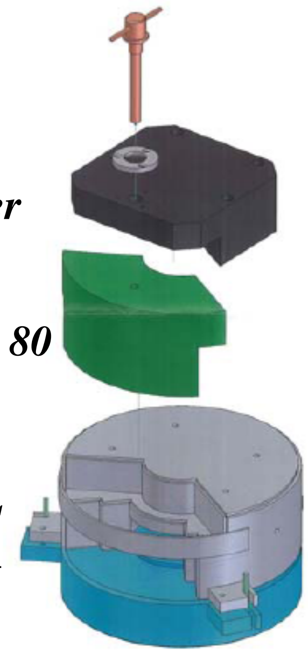
# User opportunities exist today for "MaRIE relevant" measurements at the Lujan Center

*Sample*

*Pb-lined Chalk River "Castle"*

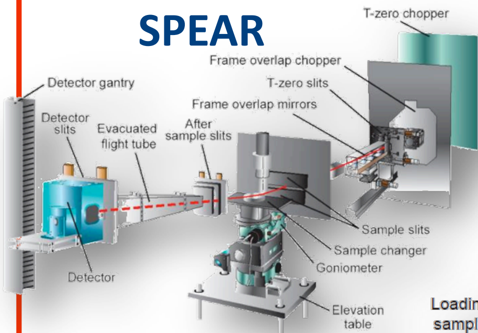
*Scattering solid angle 80 degrees*

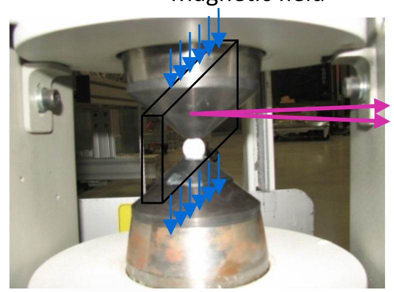
*RADSPEC instrument*



**Corrosion**

**SPEAR**



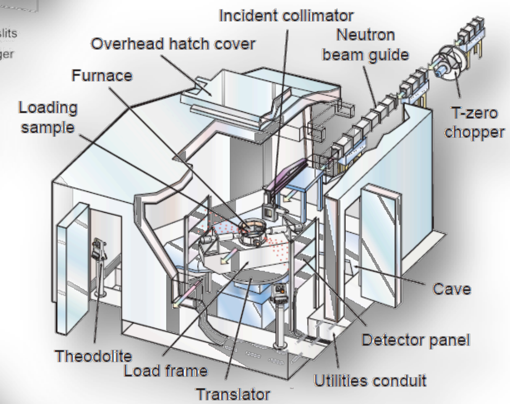




**Magnetic Contrast**

**LQD**

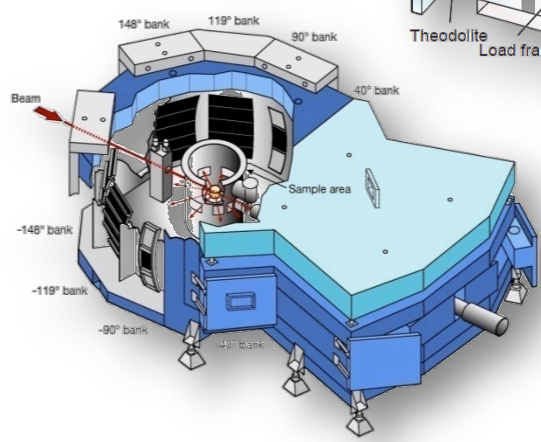
**Stress and Temperature**

**SMARTS**



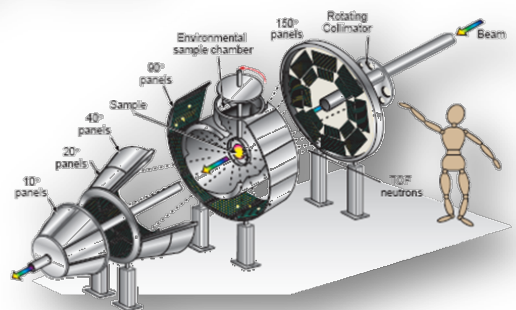

**Local structure**

**NPDF**



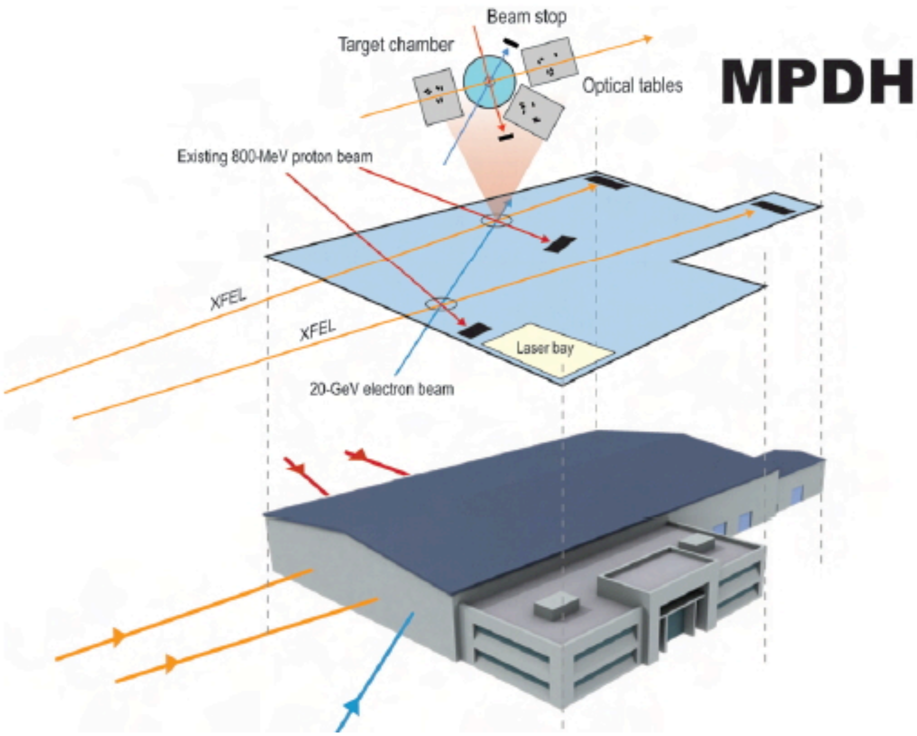

**Texture**

**HIPPO**

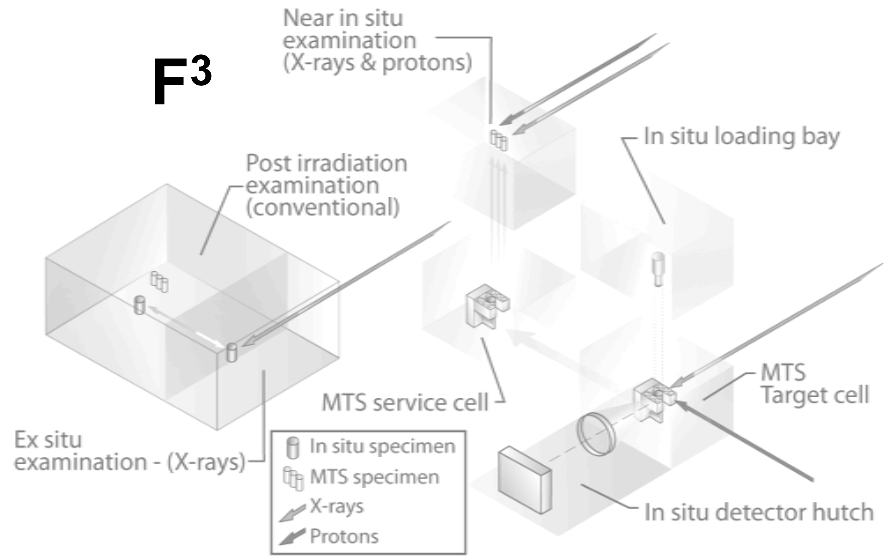


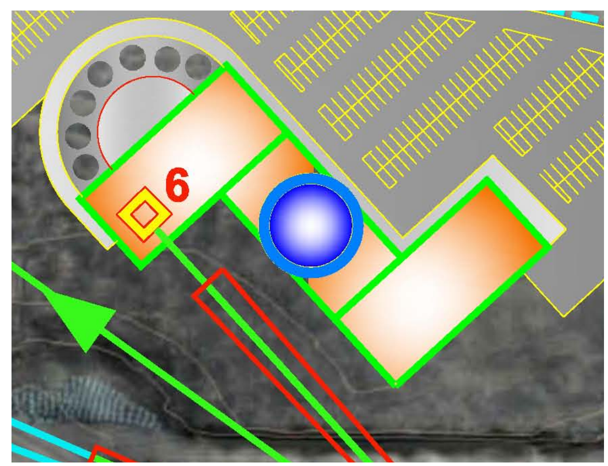
# Preconceptual facility designs enable cost/risk/benefit analysis and cost estimates

MPDH




F³




M4

# MaRIE capabilities can be realized through a phased approach

Enabling r&d

Electron accelerator → photon source

(hard, coherent, brilliant photons)

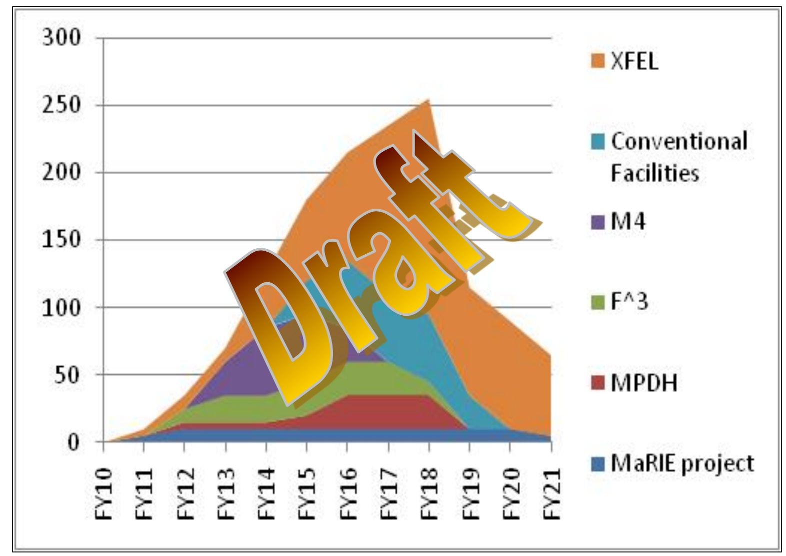
Enabling r&d

In situ synthesis and measurement capabilities

(MPDH, M4,F$^3$)

Proton accelerator → Irradiation Capability

(e.g., *Linac risk mitigation, MTS*, Fusion Upgrade)




FY09 FY11 FY13 FY15 FY17 FY19 FY21

# MaRIE will be the first capability with unique co-located tools necessary to revolutionize materials in extremes

- A mission need exists for prediction and control of materials in extreme environments
- MaRIE will provide simultaneous in situ, transient measurements on real materials in relevant extremes coupled to directed synthesis and characterization through predictive theory
- Building on existing capabilities at LANL, MaRIE provides unprecedented international user resources
- MaRIE facility definition is being driven by community-validated performance gaps & functional requirements